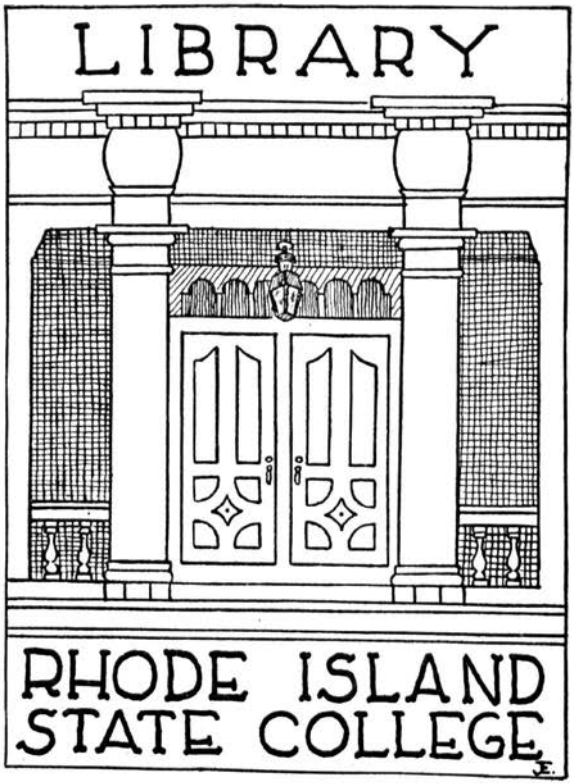
THE ROMANCE OF THE ATOM

BENJAMIN HARROW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THE ROMANCE OF THE ATOM

BY THE SAME AUTHOR

EMINENT CHEMISTS OF OUR TIME

VITAMINES: ESSENTIAL FOOD FACTORS

GLANDS IN HEALTH AND DISEASE

WHAT TO EAT IN HEALTH AND DISEASE

AN INTRODUCTION TO ORGANIC CHEMISTRY
(with Prof. A. Lowy)

EDITOR, CONTEMPORARY SCIENCE
(Modern Library)

LANGMUIR

Langmuir, one of the most brilliant of American scientists, whose theories have done much to explain chemical action (p. 102)

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THE ROMANCE
OF
THE ATOM

BY BENJAMIN HARROW

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To
IRVING LANGMUIR
MASTER CHEMIST

20967

PREFACE

An attempt is here made to describe in non-technical language, but with strict regard for accuracy, the glorious achievements of chemists and physicists in unravelling some of the profound mysteries hidden within the atom. A small portion of the book, in somewhat altered form, has appeared in *Harper's Magazine*. Dr. Langmuir, whose name is so intimately associated with advances in our knowledge of atomic structure, has been good enough to read and to criticize those portions of the book relating to his own work; however, I alone am to be held responsible for any mistakes.

If the magnificent work of Bohr receives but scant mention, it is because, in the first place, my primary object in writing the book was to explain, in a simple way, just what chemical action is; and this Langmuir's theory does admirably; further, to comprehend Bohr's theory requires a knowlege of physics and mathematics much beyond the grasp of the average reader. To "popularize" Bohr's theory is not unlike the attempt to "popularize" Einstein's theory: it cannot be done.

The last three chapters, at first sight not strictly relevant to the subject matter, need little excuse for being incorporated in the book. In our day the labours of the scientist mould the life of the citizen as never before.

BENJAMIN HARROW.

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THE ROMANCE OF THE ATOM

The ROMANCE OF THE ATOM

CHAPTER I

ALCHEMY AND THE DAWN OF CHEMISTRY

In a tract published in 1667, Helvetius, physician to the Prince of Orange, relates how a mysterious person left a mysterious package with him which contained "three large pieces of a substance resembling glass, or pale sulphur, and informed me that here was enough of the Tincture for the production of twenty tons of gold. I asked my wife to put the Tincture in wax, and I myself, in the meantime, prepared six drachms of gold. I then cast the Tincture, enveloped as it was in wax, on the lead. As soon as it was melted there was a hissing sound and a slight effervescence; and after a quarter of an hour I found that the whole mass of lead had been turned into the finest gold. . . . We immediately took it to the goldsmith, who at once declared it to be

the finest gold he had ever seen, and offered to pay fifty florins an ounce for it." *

The news spread like wildfire over the city, and everybody, from the Prince downwards, rushed to see the physician, and more particularly, his sample of gold. The sample was gold —there could be no question about that; but to manufacture more gold required not only more lead, which could be obtained easily enough, but more Tincture, which could not be obtained so easily. The stranger, the "Artist Elias," never turned up again; and since he alone possessed the Tincture, the conversion of any more lead into gold had to be postponed until the blessed day when the great artist would show himself once more. "Before he left me," writes Helvetius, "on the last day of our friendly intercourse, he told me that he was on the point of undertaking a journey to the Holy Land. May the Holy Angels of God watch over him wherever he is, and long preserve him as a blessing to Christendom."

The strange jumble of fact and fiction, and of theology and science, is what characterizes the alchemists. Superficially examined, the aim of the alchemist was to transform all base metals into gold with the help of the "philoso-

* H. D. Redgrove: *Alchemy: Ancient and Modern* (1923).

pher's stone"; but a more critical examination reveals a philosophy handed down to some extent from the Greeks and Arabs and coloured by the prevailing theology of the period. Stripped of the mystical language that pervades much of the writings of the alchemists, the philosophical background that gave rise to their experimental researches may be traced to the view that the varieties of matter are merely different modifications of earth, air, fire and water; that growth and increasing complexity gradually arise from these elementary units, giving rise to the multitudinous forms which fill the earth. Such, at least, was the view of the alchemists with regard to the evolution of metals, and probably of the "lifeless" things in general. They were, of course, too saturated with the theology of the period—embracing the greater part of the Middle Ages—to apply the evolutionary doctrine to the things that have life.

The early alchemists were mystics. They were either students of the "Kabbala," or books based on it. They were acquainted with philosophy that was handed down to them from the days of the Greeks, but in a somewhat distorted fashion. They also showed what the Greeks never had shown, but what perhaps they

had inherited from the Arabians, a love for handling materials, in addition to a desire to talk and write about them. The metals were to them symbols of the life among us. The "base" metals, such as copper and iron, corresponded to "base" men; and the "noble" metals, such as gold and silver, particularly the former, to the "noble" among us. Gold stood for beauty and for resistance to corruption (by the elements). That gold happened to be the standard used to demarcate the rich from the poor was an accident.

"Alchemy," says Bacon in his *Advancement of Learning*, "may be compared to the man who told his sons he had left them gold buried somewhere in his vineyard; where they, by digging, found no gold, but by turning up the mould about the roots of the vines, procured a plentiful vintage. So the search and endeavours to make gold have brought many useful inventions and instructive experiments to light."

Ignored until quite recently have been the two basic contributions of the alchemists, the idea of evolution and the possible transmutation of one element into another. Transmutation of the elements follows logically from the evolutionary hypothesis; for, said the alche-

mists, the various metals, such as copper, iron, silver and gold, are not really fundamentally different, but are different modifications of one and the same substance. There is, so they reasoned, something in nature which changes the elements from one type to another, and that something must be the philosopher's stone, the masterpiece of alchemistic art. To discover this stone became the all-absorbing passion of these men.

The "philosopher's stone" came to exceed the limited significance attached to it by earlier writers and experimental workers. It was no longer to be regarded merely as a substance with which the base metals could be converted into gold, but as the "elixir vitæ," the elixir of life. Says Paracelsus (1493-1541): "There is nothing which might deliver the body from mortal death; but there is one thing which might postpone decay, renew youth and prolong human life—the philosopher's stone." If you want to, you may regard Paracelsus as the forerunner of Voronoff, Steinach, and the latter's disciple, Gertrude Atherton.

History repeats itself—sometimes, at least. Until the time of the Curies, J. J. Thomson, and the rest of that little band that have played havoc with our hitherto accepted notions of the

structure of matter—which was well within the present century—our chemists and physicists, even the best of them, belittled the activities of their forerunners, the alchemists, and ridiculed their transmutation experiments. There was much to belittle and ridicule, particularly for the indiscriminate historian. A lack of an understanding of the spirit of the Middle Ages prejudiced chemists against the experiments of the alchemists. Descriptions of experiments were couched in words of obscure meaning. Nor have the historians of chemistry been sufficiently careful to sift the charlatans, whose obvious game was to get money from a credulous public, from the alchemists proper, who were God-fearing men, and whose search for the philosopher's stone was inspired not by a desire for riches, but by a passion to put a philosophical theory to the test. Redgrove claims, and one is tempted to agree with him, in part at least, that the modern period in chemistry and physics has given us many excellent manipulators but few real thinkers. During the great days of alchemy the facts were few, but there was some deep thinking. We, of course, do not want to return to the period when the laboratory was either unknown or little frequented, but we are certainly in need of more

vigorous thinking—in science and out of science.

That the heavier elements are complexes of two or more lighter elements, and that the transmutation of metals is distinctly within the realm of possibility, are statements which no scientist of to-day questions. Ignoring the somewhat questionable transmutation experiment of Sir William Ramsay, no one hesitates to accept the recent work of Sir Ernest Rutherford on the transmutation of nitrogen into hydrogen, by subjecting the former to a violent bombardment of rays obtained from radium. And has not Miethe within the last year or two claimed to have transformed mercury into gold? At any rate, if nitrogen can be changed into hydrogen, why should it not be possible, sooner or later, to change one of the "base" metals into gold?

CHAPTER II

PRIESTLEY AND THE DAWN OF MODERN CHEMISTRY

PRIESTLEY (1733-1804) occupies something of the same place in the history of chemistry that one of the more prominent signers of the Declaration of Independence occupies in the history of the United States. The analogy may be carried even a step further, for the period in which modern chemistry was born coincides pretty closely with the period which witnessed the birth of the American Republic. Priestley's great discovery, the isolation and identification of oxygen, was made in 1774. Here is his own description of the experiment:

"Having procured a lens of twelve inches diameter and twenty inches focal distance, I proceeded with the greatest alacrity, by the help of it, to discover what kind of air a great variety of substances would yield, putting them into the vessel which I filled with quicksilver, and kept inverted in a basin of the same. With this apparatus, on the first of August, 1774, I endeavoured to extract air from *mercurius calcinatus per se* [mercuric oxide]; and I presently found, by means of this lens, that air was

expelled from it very readily. Having gotten about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can express was that a candle burnt in this air with a remarkably vigorous flame. A piece of red-hot wood sparkled in it, exactly like paper dipped in a solution of nitre, and it consumed very fast." *

In this way oxygen, a constituent of the air, a constituent of water, found abundantly in many substances, and absolutely essential to life, was discovered. And with this discovery Priestley emerged definitely from the misty atmosphere of alchemy into the bright light of modern chemistry. Yet Priestley was not so much divorced from his times but that he still adhered, with amazing tenacity, to the "phlogiston" theory of burning. Substances burn, maintained Priestley, and most of his illustrious contemporaries, because they give out "phlogiston," a mysterious "something" which is present in all substances capable of burning. But that is absurd, said Lavoisier (1743-1794), the foremost of the French chem-

* See W. T. Sedgewick and H. W. Taylor: *A Short History of Science* (1918), page 307; also, T. W. Lowry: *Historical Introduction to Chemistry* (1915), page 70 *et. seq.*

ists, since a substance *after* burning weighs more than a substance *before* burning; so that burning must involve an addition to the weight of the substance, and not a subtraction. Lavoisier had indeed shown, in a series of epoch-making experiments, that this addition was due to that very oxygen which was first isolated by Priestley.

For a scientist Priestley was anything but critical. In fact, on the subject of phlogiston (which comes from a Greek word meaning "burned") he resembles rather the alchemist of the Middle Ages than the scientist of our day. Lavoisier's balance, with the help of which the great Frenchman demonstrated what really took place when substances burned, and the facts it revealed, influenced the Englishman little: he chased after phlogiston much as Sir Oliver Lodge chases after an ether. To Priestley discoveries in science were largely a matter of chance: you did one thing, and then another, with no particular object in view, until some day Fortune smiled on you, and you isolated a gas which supports combustion even better than does air. It would, however, be poor justice to Priestley to draw the inference that he owes his fame to chance alone. As a matter of fact, he possessed the inventive faculty to a high

degree; and though shaky in his logic, was often remarkably quick in seizing upon essentials. This combination of the instinct of the prophet with the technique of the expert manipulator he shared with another famous chemist of more recent date, William Ramsay.

Had Priestley confined himself to science alone he might have lived and died in his beloved England, honoured as one of her worthies. His active mind, however, roved far and wide. The son of a Nonconformist, he held heterodox views on the subject of religion and never failed to express these views in public. Like Tolstoy in our own day, Priestley considered his religious expositions all-important. Chemistry was to him little more than an agreeable pastime: he went to his laboratory in much the same spirit that the suburbanite goes to his golf club. By profession a clergyman, by avocation a scientist, passionate lover of truth as he saw it, and ever ready to shout this truth from the housetops, he was forever coming into conflict with "law and order." In 1791 a group of Birmingham citizens decided to celebrate the fall of the Bastille. This aroused the community. Word was passed around that the leading spirit in this "radical" celebration was Joseph Priestley, arch-heretic and chemist; and the

mob decided to mete out justice. They burned and sacked his chapel and house, and Priestley himself narrowly escaped from their clutches. He fled to London and hid himself in Hackney, then a suburb of the metropolis. At the end of three years, in 1794, disheartened and disgusted, he decided to emigrate to America.

While Priestley was crossing the Atlantic to escape persecution, his great rival, Lavoisier, had come in conflict with the leaders of the French revolution. He was an aristocrat. He had been Farmer-General and tax gatherer for the royal government. Marat, "l'ami du peuple," would have none of him. Lavoisier was an aristocrat; that was enough for one execution. But Lavoisier was a bad chemist in addition! "Lavoisier," writes Marat, under the flattering title of *Modern Charlatans,* "the putative father of all the discoveries that are noised about, and having no ideas of his own, snatches at those of others; but having no ability to appreciate them, he rapidly abandons them and changes his theories as he does his shoes." And once again in the history of mankind a Galileo is made to suffer—this time not by an Inquisition and a Religion, but by the People and in the name of Freedom. A wise man of the times remarked, in private, that it

took but an instant to cut off Lavoisier's head, though a hundred years will not suffice to produce one like it.

But we must hasten back to Priestley. What representative Americans thought of him is well expressed by Benjamin Franklin. "I do not," he writes to a friend, "call him honest by way of distinction, for I think all heretics I have known have been virtuous men. They have the virtue of fortitude, or they would not venture to own their heresy; and they cannot afford to be deficient in any of the other virtues, or that would give advantage to their enemies. . . . Do not misunderstand me. It is not to my good friend's heresy that I impute his honesty. On the contrary, 'tis his honesty that has brought upon him the character of heretic." *

In New York Priestley received a welcome such as a successful general might get. The newspapers had glowing accounts of "the illustrious Dr. Priestley," and representatives of various organizations were on hand to do him honour. James Nicholson, the president of the Democratic Society of the City of New York, said in his address: "The governments of the old world present to us one huge mass of in-

* See Edgar F. Smith: *Priestley in America* (1921).

trigue, corruption and despotism—most of them are now basely combined to prevent the establishment of liberty in France, and to effect the total destruction of the rights of man. Under these afflicting circumstances we rejoice that America opens her arms to receive, with fraternal affection, the friend of liberty and human happiness." The Tammany Society, consisting, in 1794, of a "numerous body of freemen who associate to cultivate among them the love of liberty and the enjoyment of the happy republican government under which they live," were also there to do Priestley honour; they "learnt with regret and indignation the abandoned proceedings of those spoilers who destroyed your house and goods, ruined your philosophical apparatus and library, committed to the flames your manuscripts, pried into the secrets of your private papers, and in their barbarian fury put your life itself into danger."

The philosopher, surrounded by sympathetic friends on all sides, settled with his two sons on a farm in Northumberland, Pennsylvania; and during the remainder of his life—some ten years—busied himself with writing a church history and with carrying out experiments in support of the "phlogiston" theory of burning.

CHAPTER III

THE ATOM

"It seems probable to me," writes Sir Isaac Newton, "that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles; of such sizes and figures, and with such other properties, and in such proportions to space, as most conduced for the end for which he formed them; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break to pieces; no ordinary power being able to divide what God himself made One, in the first creation." *

Newton's *corpuscular* theory of matter is what one might have anticipated from the author of the corpuscular theory of light. This theory of matter, however, did not originate with the Cambridge astronomer. Centuries before his time the Greek philosophers had given earnest thought to the question: can matter be

* T. M. Lowry: *Historical Introduction to Chemistry* (1915), page 291.

subdivided indefinitely? Some claimed that it could not; others, that it could. Some claimed that a superman, with eyes sharp enough and with tools of an appropriate kind, could take a piece of gold, and divide it and subdivide it, and continue to subdivide it to the end of time; others claimed that such a superman would ultimately reach a state beyond which no further subdivision would be possible. The name *atomos,* or *atom,* was suggested for the particle "which cannot be cut in two."

Without any facts known to support it, the idea of an atomic structure of matter remained an interesting curiosity until the beginning of the nineteenth century. Then the Englishman, John Dalton (1766-1844), revived it and extended it to explain a number of laws in chemistry which even in his day had already become firmly established. One of these laws, and the most fundamental, is that elements combine in definite proportions by weight to form compounds. Common salt, or to give it its chemical name, sodium chloride, consists of the elements sodium and chlorine combined in such a way that for every 23 parts by weight of sodium there are found to be 35½ parts by weight of chlorine. It does not matter at all whether the salt is obtained from sea water, or from a salt

DALTON

Dalton, the founder of the atomic theory (p. 28)

MENDELÉEFF

Mendeléeff, author of the periodic classification of the elements (p. 34)

mine, or by the combination of the elements sodium and chlorine: provided the salt is chemically pure, analysis reveals that the proportion of sodium is to chlorine as 23 is to 35½. And what is true of salt is true of every one of the thousands of compounds known to the chemist: every compound is made up of two or more elements combined together in definite proportions by weight.

The law of *definite proportions* needed an explanation, and Dalton provided one. Let us assume, he argued, that elements like gold, sodium, hydrogen and chlorine, representing the simplest types of matter, are made up of infinitesimally small particles called atoms. Let us assume, further, that the atoms of any one element are the same, but that they differ from the atoms of any other element. Suppose one difference between the atoms of one element as compared with the atoms of another is due to a difference in weight, such that the weight of a sodium atom is to the weight of a chlorine atom as 23 is to 35½. Since atoms, according to the Daltonian theory, are the smallest conceivable particles, the smallest part of sodium which can enter into chemical combination with chlorine is one atom, and, vice versa, the smallest part of chlorine which can enter into

chemical union with sodium is one atom. Assuming the simplest combination, one atom of sodium combines with one atom of chlorine to form sodium chloride. Since the respective weights of the atom, are as 23 is to 35½, then it is no wonder that analysis of sodium chloride reveals these proportions. And if instead of assuming the reaction to involve two single atoms, we assume that a million million atoms of sodium combine with a million million atoms of chlorine, the analysis of the resulting compound must still show the relative proportions of 23 is to 35½.

It may at once be said that Dalton's *Atomic Theory* is to-day more firmly entrenched than ever. Atoms are real pieces of matter, inconceivably small, to be sure, and yet nevertheless real. The rule laid down by Dalton that the smallest particle of matter which can take part in a chemical change is an atom, is firmly believed by every physicist and chemist. The modifications necessary as a result of more modern research embrace the view that whereas *chemical* reactions involve reactions *between* atoms, there may be other types of reactions, such as those due to radioactivity, which involve changes *within* the atom. Dalton was wrong when he assumed that the atom is the smallest

particle imaginable, for to-day we are familiar with the electron, which is smaller than the atom, and which, indeed, constitutes but a small part of the planetary system of the atom; but he was right in assuming that an atom is the smallest particle capable of taking part in a *chemical* change. We know that atoms are entities, though the average diameter of the atom is not more than one-three-hundred-millionth of an inch; and, still more remarkable, we know that electrons are entities, though the diameter of an electron is probably not more than one-hundred-thousandth that of an atom, and its weight about one-two-thousandth that of the lightest atom known, namely hydrogen!

The great physicists of an earlier generation, among them Faraday, Kelvin and Helmholtz, attempted an estimation of atomic sizes in a number of ingenious ways. Some dyes, for example, will exhibit colour even when diluted one hundred million times; which can be interpreted as meaning that the smallest weighable particle of such a dye may be divided into one hundred million parts. Faraday prepared films of gold the thickness of which he estimated to be one-hundred-millionth of an inch. Continuous films with soap bubbles and with oil were obtained when the thickness could hardly have been one-

eighth the thickness of Faraday's gold leaf. Further and more complicated experiments and calculations, involving such phenomena as viscosity and conduction of heat in gases, yielded a figure which indicated that six hundred million million atoms occupy one cubic inch of space.*

Since these numbers have no more meaning than the war indemnity quotations calculated in billions, let us resort to a few analogies. If a drop of water were magnified to the size of the earth, the constituent atoms would be about the size of footballs. Or, to use a variation of this analogy, if the constituent atoms in a tumbler of water could all be labelled for later identification, and the water were then mixed with all the water in the world, and if, after thorough mixing, the tumbler were again filled, it would contain two thousand of the original atoms. Three years ago, when the paper marks, at one moment, were worth sixty cents per trillion, Dr. Foote, of the Bureau of Standards, calculated that one *paper* mark would still be enough to buy three billion *gold* atoms!

The limit of vision of our most powerful ultra-microscope is a particle with a thickness

* See D. F. Comstock and L. T. Troland: *The Nature of Matter and Electricity* (1919), page 54.

of about one-three-millionth of an inch, which is still two hundred times the width of the calculated atom. Yet science triumphs in unexpected ways; for in recent studies on the discharge of helium atoms from radioactive substances, it has been found possible to calculate the individual helium atoms by the scintillations set up when they strike certain phosphorescent substances. Sir Ernest Rutherford, the author of this ingenious experiment, counts the number of such scintillations within a given time, measures the volume of gas collected, makes a number of calculations, and coolly announces that there are 77 billion billion atoms of helium per cubic inch of the gas!

CHAPTER IV

THE ATOM: MENDELÉEFF

"This investigation is dedicated to the memory of a mother by her youngest offspring. Conducting a factory, she could educate him only by her own work. She instructed by example, corrected with love, and in order to devote him to science, she left Siberia with him, spending in this way her last resources and strength. When dying she said, 'Refrain from illusions and insist on work and not on words. Patiently search divine and scientific truth.' She understood how often dialectical methods deceive, how much there is still to be learned, and how, with the aid of science, without violence, with love but firmness, all superstition, untruth and error are removed, bringing in their stead the safety of undiscovered truth, freedom for further development, general welfare, and inward happiness. Dimitri Mendeléeff regards as sacred a mother's dying words."—From Mendeléeff's preface to his work on *Solutions*.

We must look to Mendeléeff (1839-1907) and his Periodic Classification for the first signs of skepticism in the view that the atom is the ultimate particle of matter. Mendeléeff published his paper in 1869. Briefly, what he showed was as follows: You have some eighty odd elements, like hydrogen, silver, iron, oxygen, etc., composed, as Dalton postulates, of atoms of these elements. If we take the lightest of these atoms, hydrogen, and call its weight 1, then the atom

MENDELÉEFF'S PERIODIC CLASSIFICATION OF THE ELEMENTS

Series	Zero group	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII		
0	*x*	—	—	—	—	—	—	—	—	—	—
1	*y*	Hydrogen, H = 1.008	—	—	—	—	—	—	—	—	—
2	Helium, He = 4.0	Lithium, Li = 7.03	Beryllium, Be = 9.1	Boron, B = 11.0	Carbon, C = 12.0	Nitrogen, N = 14.04	Oxygen, O=16.0	Fluorine, F = 19.0	—	—	—
3	Neon, Ne = 19.9	Sodium, Na = 23.05	Magnesium, Mg = 24.1	Aluminum, Al = 27.0	Silicon, Si = 28.4	Phosphorus, P = 31.0	Sulphur, S = 32.06	Chlorine, Cl = 35.45	—	—	—
4	Argon, Ar = 38	Potassium, K = 39.1	Calcium, Ca = 40.1	Scandium, Sc = 44.1	Titanium, Ti = 48.1	Vanadium, V = 51.4	Chromium, Cr = 52.1	Manganese, Mn=55.0	Iron, Fe=55.9	Cobalt, Co=59	Nickel, Ni=59(Cu)
5	—	Copper, Cu = 63.6	Zinc, Zn = 65.4	Gallium, Ga = 70.0	Germanium, Ge = 72.3	Arsenic, As = 75.0	Selenium, Se=7.0	Bromine, Br = 79.95	—	—	—
6	Krypton, Kr = 81.8	Rubidium, Rb = 85.4	Strontium, Sr = 87.6	Yttrium, Y = 89.0	Zirconium, Zr = 90.6	Niobium, Nb = 94.0	Molybdenum, Mo = 96.0	—	Ruthenium, Ru=101.7	Rhodium, Rh=103.0 Palladium, Pd=106.5 (Ag)	
7	—	Silver, Ag = 107.9	Cadmium, Cd = 112.4	Indium, In = 114.0	Tin, Sn = 119.0	Antimony, Sb = 120.0	Tellurium, Te = 127	Iodine, I = 127	—	—	—
8	Xenon, Xe = 128	Cæsium, Cs = 132.9	Barium, Ba = 137.4	Lanthanum, La = 139	Cerium, Ce = 140	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—
10	—	—	—	Ytterbium, Yb = 173	—	Tantalum, Ta = 183.0	Tungsten, W = 184	—	Osmium, Os=191	Iridium, Ir=193	Platinum, Pt=194.9 (Au)
11	—	Gold, Au = 197.2	Mercury, Hg = 200.0	Thallium, Tl = 204.1	Lead, Pb = 206.9	Bismuth, Bi = 208	—	—	—	—	—
12	Nt 222.4	—	Radium, Rd = 224	—	Thorium, Th = 232	—	Uranium, U = 239	—	—	—	—

of silver can be shown to weigh 108 times, the atom of gold 197 times, and the atom of oxygen 16 times that of hydrogen. The numbers 108, 197 and 16 represent the *atomic* weights of the elements silver, gold and oxygen. Mendeléeff now showed that these atomic weights could be utilized for the purpose of bringing out family resemblances among the elements; and all that was really necessary to show this—to state the case in its simplest form—was to group your elements in lots of eight, starting with the lightest, hydrogen, and working your way up to the heaviest, uranium. Where there are brothers and sisters there must be fathers and mothers; and when you find that according to Mendeléeff's grouping such elements as lithium, sodium and potassium, or chlorine, bromine and iodine, show blood ties, and all your laboratory experience abundantly confirms such relationships, then you begin to wonder whether the elements, and the atoms of which the elements consist, are really the fundamental substances in nature they are supposed to be. Whatever philosophy there is in us urges us to the view that the elements represent but the different branches of one tree, and that they have their ultimate origin in some inorganic equivalent for the ameba.

Mendeléeff was not the first to believe that the elements were not merely disconnected bodies. Döbereiner, in 1829, pointed out that a number of the elements could be grouped in "triads" in such a way that the arithmetic mean of the atomic weights of the first and the third would give that of the second. Dumas, some thirty years after Döbereiner, advanced a similar hypothesis, extending it to groups in organic chemistry. But to Newlands, an Englishman, belongs the honour of having been the first to see fairly clearly how the eighty odd elements could be grouped to show their relationships. In a paper read before the English Chemical Society in 1866, Newlands showed that the elements could be arranged in groups of eights along horizontal lines in such a way that elements in the vertical columns would be those with similar properties. The law of *octaves* was given to this grouping of eights.

The reception accorded the theory by Newlands' fellow-chemists was anything but encouraging. One ostentatious busybody wished to know whether Newlands had tried to arrange the elements according to their initial letters! Another suggested new possibilities in the field of music with the law of octaves! The upshot

of the whole affair was that poor Newlands was sent home thoroughly ridiculed, and his paper was refused publication in the society's journal. That, however, did not prevent the Royal Society from making some amends twenty-one years later by awarding him its Davy Medal for the very paper which its sister organization had refused to print! It must be added, however, in excuse for the skepticism of the scientists of the day, but in no excuse for their arrogance, that Newlands had not put his theory to as thorough a test as he might have done. In its incomplete form, its suggestions were too vague for men steeped in experimental work. But Mendeléeff's paper three years later removed most of the objections and forced the attention of the chemists to his scheme. Mendeléeff left nothing for granted; his statements were accompanied by carefully selected experimental evidence.

What were the immediate results of Mendeléeff's periodic classification? To begin with, a number of the elements did not fit in with his scheme. Forthwith he announced that the fault lay with the incorrect atomic weights which had been assigned to these elements. Mendeléeff proved his case in all such instances.

Thus, to take one example, the then accepted atomic weight for gold was 196.2; accordingly, it should have been placed before such elements as platinum, iridium and osmium, with atomic weights of 196.7, 196.7 and 198.6, respectively. But Mendeléeff insisted upon putting gold after these elements, claiming that their atomic weights, and not his table, needed revision. Subsequently, a redetermination of the atomic weights gave the following results: osmium 190.9, iridium 193.1, platinum 195.2 and gold 197.2; which was precisely the order in which Mendeléeff had placed them.

But he did something far more daring. The grouping according to Mendeléeff's scheme resulted in certain gaps being left unfilled. This, said he, was due to elements which awaited discovery. By a careful consideration of the properties of adjacent elements, the great Russian *predicted* the properties of these undiscovered elements.

A case will be cited. To one of the unknown elements Mendeléeff gave the name *ekasilicon*, and certain properties were predicted for it. In 1886 Winkler discovered germanium, which showed identical properties with this *ekasilicon*, as the following comparison will show:

	Mendeléeff's Ekasilicon	Winkler's Germanium
Atomic weight	72	72.5
Density	5.5	5.469
Density of oxide	4.7	4.703
Density of chloride	1.9	1.887
Boiling point of chloride	less than 100 degrees centigrade	86 degrees centigrade

These wonderful predictions did more to convince scientists of the validity of the hypothesis than anything else could have done. The soundness of a theory is best exemplified by the use to which it can be put. Does it explain anomalies? Does it guide along future paths of investigation? The Periodic Classification has more than fulfilled these requirements. It stands out as prominently in the history of chemistry as does Dalton's Atomic Theory, which is at the very foundation of the science. Some of the most startling discoveries of our time—some of the rare gases of the atmosphere and a number of the radio-elements are attributable to the Periodic Classification.*

* It should be mentioned that Chancourtois in France, and Lothar Meyer in Germany, also suggested a periodic classification of the elements. Lothar Meyer, in particular, with his atomic volumes—the volumes occupied by the atomic weights of the elements—was able to uncover some striking analogies. The papers by Lothar Meyer and Mendeléeff were published in the same year, 1869. The time was unquestionably ripe for such a formulation. Somewhat similarly, Darwin and Wallace, ten years earlier, unfolded the origin of species quite independently of one another.

CHAPTER V

THE ATOM: CROOKES

THE newer knowledge regarding the structure of matter dates back to the eighties of the last century, when Sir William Crookes (1832-1919) was still active in the laboratory and had not, as yet, joined the Lodges and the Richets in their get-there-quick flights to the land of the dead. Electricity was the tool chosen by Crookes. The electrolytic studies of Faraday and the electro-magnetic theory of light, due to Clerk Maxwell, made it appear plausible that electricity and matter were not two disconnected entities. When, therefore, a high-tension current from an induction coil—familiar to-day to every youngster with his "radio" set—was passed through a tube from which the air had been exhausted as much as possible, and Crookes was able to demonstrate to a British Association audience that rays were shot out from the cathode which gave rise to fluorescence and heat when they struck objects, the probability that these rays, these cathode rays,

represented a new state of matter (as suggested by Crookes) seemed a logical interpretation. Crookes in his experiment made use of a property with which we are now thoroughly familiar, namely, that when atoms are charged with electricity (and they become "ions" and are "ionized"), their existence and behaviour can be studied much more easily than when they are *un*-ionized. Charged with electricity, the presence of a few thousand atoms can be easily detected, while the most refined methods of chemical analysis will hardly detect less than a million million uncharged atoms.

"The true man of science," writes Fournier D'Albe,* "worships but one god—truth. He despises the ecclesiastics for teaching half-truths for the sake of moral influence; the politician for dressing up truth in a partisan guise; and the business man for subordinating truth to personal gain." This view may be true of the "true man of science," but I have yet to find him. That is to say, the scientist may be, and usually is, the truth-seeker so long as he is in the laboratory, but out of it he becomes D'Albe's ecclesiastic, politician and business man. His scientific knowledge guides him in

* E. E. Fournier D'Albe: *The Life of Sir William Crookes* (1925).

his experiments, but it has so far failed to guide him in the affairs of the world. He has, one may say, two compartments in his brain: one compartment, unique to him and his kind, for his science, and another compartment, common to all men, for all things outside of science. The tragedy is that the lessons of science are either not learned, or else, if learned, are not applied. The general public belongs to the former category and most scientists to the latter.*

Sir William Crookes was no "true man of science" in my sense, though he easily became one of England's foremost scientists. For fertility of imagination in his chosen field, it is doubtful whether even England, whose scientific soil is so exceptionally fertile, has produced another his equal. In fact, it was this imagination, which sometimes ran riot, that led him, even early in life, into spiritualism. But Crookes, the great scientist, the President of the Royal Society, the discoverer of a new element, the inventor of the radiometer, the "father" of the modern work on the structure of the atom, was religious in the "ecclesiastical" sense, studied economics with the eye of a politician, and managed his business affairs in a manner which Babbitt, the unreformed,

* See page 146 for a further discussion.

might have envied. What is really quite remarkable in the life of Crookes is that he should have risen to become a highly original investigator in the more theoretical aspects of the science without ever having had a university education, or very much even of a secondary education. Perhaps it is the very atmosphere of England; for I can now recall three other Englishmen, speculators of the very highest order, who were self-made men: Faraday, Joule and Dalton.

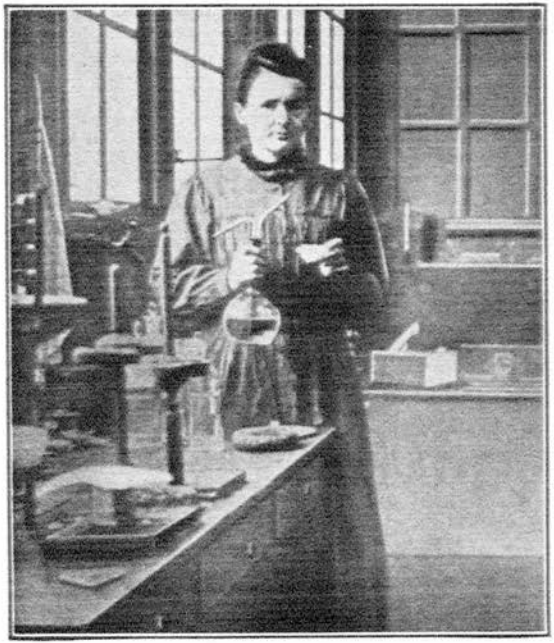
The work by which Crookes will best be known to future generations is that dealing with the phenomena within an exhausted tube —a tube from which most of the air or other gas has been removed—when under the influence of electricity. His first contribution to this subject did not deal with the influence of electricity. He invented the radiometer, an instrument now common enough in the windows of many opticians. In its essential features, the radiometer consists of a partially exhausted tube in which is an aluminum wheel with four vanes, one side of each of these being polished and the other blackened. In sunlight these vanes are in constant rotation, due to the fact that the blackened faces become hotter than the polished ones. "Rays of light," writes

Crookes, "fall on the white surfaces and are simply reflected again; but falling on the black surfaces they are absorbed, and, raising the temperature, produce the molecular disturbance which causes motion." The radiometer, when first shown, looked like a perilous approach to some kind of perpetual motion, and when it was put on exhibition in 1874, Crookes immediately leaped into the limelight. From then on, to the year of his death, 1919, Crookes, with the possible exception of Ramsay, was the most "popular" among all English chemists.

From the radiometer to the vacuum tube was but a step, and that led Crookes to the very threshold of the territory covered by modern physicists in their studies of the structure of the atom. For he noticed that in this exhaust tube, containing two platinum wires (electrodes) connected with a source of current, there were "dark spaces" of "molecular disturbance" projected from the cathode; in reality, a space filled with negative particles of electricity, or electrons, which Crookes called "radiant matter." "These phenomena in these exhausted tubes," wrote Crookes in one of his communications to the Royal Society, "reveal to physical science a new world—a world where

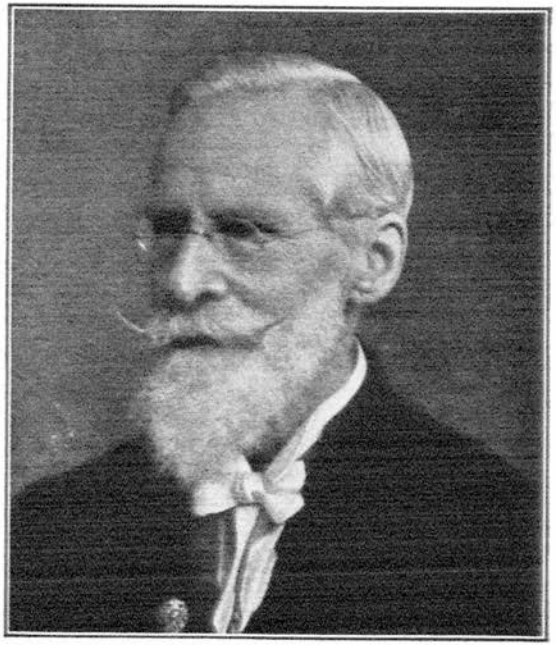
matter exists in a fourth state." Then he goes on: "In studying this fourth state of matter, we seem at length to have within our grasp and obedient to our control the little indivisible particles which, with good warrant, are supposed to constitute the physical basis of the universe. In some of its properties, radiant matter is as material as a table, while in other properties it almost assumes the character of radiant energy such as we get from the sun. We have actually touched the borderland where Matter and Force seem to merge into one another, the shadowy realm between Known and Unknown, which for me has always had peculiar temptations. I venture to think that the greatest scientific problems of the future will find their solution in this borderland, and even beyond; here, it seems to me, lie ultimate realities, subtle, far-reaching, wonderful." Prophetic words these, when you remember that they were written in the eighties of the last century.

Crookes's plunge into spiritualism is not so hard to understand if we take into consideration his investigations dealing with the "Fourth State of Matter," a subject which brought him to the very precipice of the science of his day, and gave him, so he thought, a view of the



M. Curie

Madame Curie, the discoverer of radium (p. 54)



CROOKES

Crookes, an early worker in sub-atomic phenomena (p. 41)

promised land. As a matter of actual fact, Crookes had begun to play with "spirits" years before his discovery of the electron. His fiery imagination would not be stayed by the balance or the burette. "The unknown has always had peculiar temptations for me," he writes. He leaped—and, I believe, landed on quicksand. There are some interesting and, to me, pitiful accounts of séances given in D'Albe's biography. There you may read of chairs being knocked about by "nothing," of tables floating six inches above the ground, of "Mrs. Herne being carried right up, floating across the table, and dropping with a crash of pictures and ornaments at the other end of the room," of "sweet voices, clear as a bell," high above the heads of the company, of the accordion floating around the room, of loud raps being heard from different parts of the table, etc., etc. "I feel it impossible," writes Crookes to a friend, "to convey the intense feeling of genuineness and reality which they caused in our minds." Home, his favourite "medium," was later exposed as a fraud. Still this did not stop him from making acquaintances with other mediums. As late as 1916, after the death of his wife, he held séances in his house. A "medium" and her daughter sat with Crookes in

the dark room off his laboratory. A musical box tinkled out its tune, and the old man sat patiently for the signs of "miracles" which would tell him of the presence of his beloved partner. What an incongruous mixture of glory and folly is man!

CHAPTER VI

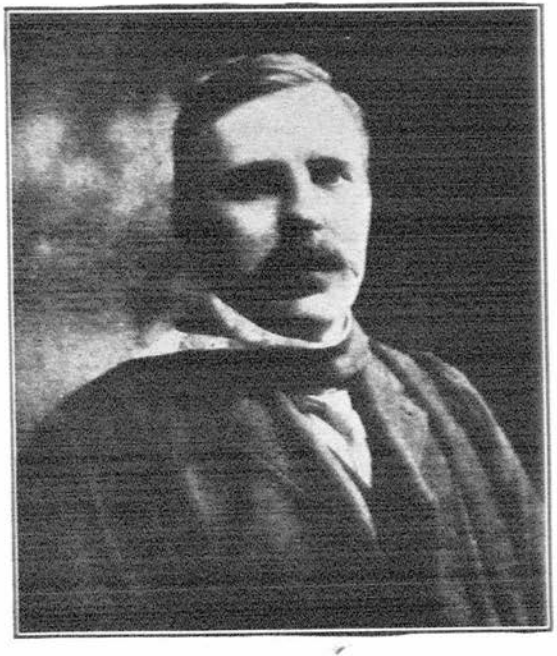
THE ATOM: THE ELECTRON

THE actual discovery and measurement of the electron (from the Greek word meaning "amber," a substance which gives rise to "negative" electricity when rubbed) must, however, be attributed to J. J. Thomson (1856 —), one of a brilliant band of workers in the Cavendish Laboratory in Cambridge, England, who began his experiments in 1897. The apparatus used was based on the one employed by Crookes, but with many modifications. The experimental details and the mathematics involved are such as to make a description of the experiment quite impossible here. Suffice it to say that using Crookes's discovery that the cathode rays (or as we call them now, the electrons) can be bent by the action of a magnet, he measured the magnitude of this bend and compared it with the strength of the magnet employed, and this gave him the basis for the calculation of the weight of these electrons. To determine the number of such electrons, and thereby obtain

a means for calculating the weight of individual electrons, use was made of a discovery by Wilson, a pupil of Thomson's, who showed that when electrons travel through water vapour they collect a little cloud, and thereby become large enough to be seen through a powerful microscope. By this means even the path of a free electron can be photographed.

Still more exact measurement by Millikan (1868 —), the American physicist, makes these facts as certain as any man-discovered "facts" can be: that the electron is a negative particle of electricity of such weight that 1700 of them weigh no more than the lightest atom known; that it is a more fundamental unit than the atom, for exactly the *same* electron is detected in *different* elements, whereas the atoms of one element differ from the atoms of another; that, since the electron is a particle of electricity, and the eighty odd elements which go to the formation of the material world around us all contain electrons, matter must be considered electrical in origin, and the electron as one of the fundamental units of matter (and therefore of electricity). (See note at end of chapter.)

That a current of electricity should be regarded as electrons *in motion* is not one of the



E Rutherford

Rutherford, who has contributed much to the structure of the atom (p. 103)

THOMSON

J. J. Thomson, who has paved the way for our knowledge of electrons and protons (p. 49)

least interesting results of this work. That, furthermore, the disintegration of radium should result in the discharge of a number of rays, one group of which, the *beta* rays, have been proved to be identical with the electron studied by Thomson, Millikan and others, is further evidence that this minute particle takes its place in the very early history in the evolution of the elements, and, therefore, of matter. Whether it is *the* fundamental unit of matter, as some enthusiasts have proclaimed, is quite another thing. In one age, the atom; in our own, the electron; fifty years from now—who knows?—a particle, *x*, still smaller than the electron! Perhaps we are already on the eve of it in Planck's unit of radiant energy, the *quantum!*

NOTE

Millikan's work is of such fundamental importance that, to satisfy the curiosity of some readers, I shall quote him from one of his own articles (see my *Contemporary Science,* Modern Library series, page 15): "We took plates with a field of ten thousand volts between them, with a little hole in the top plate, and blew an oil spray above the top plate so as to get an electrically charged body just as small as we could; for we expected that the frictional process involved in

blowing the spray would charge the drops; and this, indeed, it was found to do. We let one of these drops come into the space between the plates, and then moved it up and down by an electrical field, throwing it on the field as it came close to the bottom plate, and throwing it off as it approached the upper one. And so we kept that oil drop going up and down between the plates, in the hope that it would capture some of the ions which we knew existed in the air, put there by radium or other agencies. The drop met our fullest expectations. It captured ions frequently and signalled the fact of each capture to the observer by the change in its speed in the field. For the oil drop is an electrically charged body, and in a given field it moves with a definite speed. If, however, it captures an ion, its charge increases or decreases, and hence its speed increases or decreases. If the charges (which are the electrons) on ions are all alike, then we can only get one particular change in speed. If the charge that is already upon it, put there by the frictional process, is built up out of these same units, then the total speed which the field will impart must be an exact multiple of the change in speed which the capture of an ion produces. In other words, if electricity is atomic in structure, you cannot get in a given field anything except a definite number of speeds, which will make an arithmetical series; that is, which will come up by steps—one, two, three, etc. That is exactly what we found. We have experimented with thousands of drops and scores of different substances,

BOHR

Bohr, author of a theory dealing with the structure of the atom (p. 125)

MILLIKAN

Millikan, who has measured the electron (p. 50)

and they always work exactly that way. But positively and negatively charged drops are found to act quite the same way, showing that both positive and negative charges are built up of specks of electricity. Further, we can count the number of those specks, which we will call electrons, in a given drop, with the same certainty with which you can count the number of fingers on your hands. And again since Rowland showed that an electrical current is nothing but a charge in motion, you have here proof that the electric current that goes through the lamps we use, for example, is nothing but the motion of a certain number of electrical specks through or over the filament of the lamp. Add to that J. J. Thomson's discovery made in 1881, that an electrical charge possesses inertia, the only distinguishing property of matter, and you have made it perfectly legitimate to say that an electrical current in a wire is a definite, material, granular something that is moving along that wire."

CHAPTER VII

THE ATOM: MADAME CURIE

Much of what we know of the structure of the atom would still remain a mystery but for the isolation, by Madame Curie, of the most remarkable of all elements, radium, and for the elucidation of its properties. For in radium we see Nature at work breaking up the atoms of the element before our very eyes, and allowing us, incidentally, a peep into the holy of holies—the internal structure of the atom.

Madame Curie (1867 —) has been called the greatest of women scientists. I do not like this description at all. To me it seems to say, "The intelligence of women, if you must know it, is pretty limited; but Madame Curie is an exception to the general rule." Among scientists, women and men, Madame Curie compares most favourably with the half dozen of the very greatest. She is one of the most distinguished scientists of all time. And I say this having in mind not only her discovery of radium, but her research work which has followed since that discovery. Her various monographs and tech-

nical articles all bear the stamp of genius. In every one of them we find a happy blending of the bold speculator and the patient experimenter. In every one of her contributions we see evidence of a master mind—of that particular variety of the master mind which belongs to the scientific species, which forever dreams and forever tests.

I must also take issue with the group of people who regard her husband, Pierre Curie, as the real discoverer of radium and look upon his wife as an assistant who shared in his work. As a matter of fact, the reverse is true; and this can be said without the slightest intention of belittling Pierre Curie's achievements. For what are the facts in the case? Becquerel, in following up Röntgen's discovery of X-rays, showed that the salts of uranium, a rare element, emit peculiar rays—rays which, for example, have the power of affecting a photographic plate in a manner similar to the way the rays from the sun affect it. This was in 1896. Marie Curie was 29 years old at the time and married to Pierre Curie, a struggling and promising instructor in physics, who divided his research work between mineralogy, optics and electricity. Madame Curie, quite independently of her husband, undertook to find

whether any other elements besides uranium emit these rays. Of all the elements examined, only thorium showed this characteristic. And then came a most important observation, namely, that the mineral pitchblende, from which uranium is extracted, emits a ray-activity, or "radio-activity" (a word coined by Madame Curie) several times greater than uranium itself. "I then made the hypothesis," writes Madame Curie, "that pitchblende contains in small quantity a substance much more strongly active than uranium itself. This substance would not be one of the known elements, because these had already been examined; it must therefore be a new element. I had a passionate desire to verify this hypothesis as rapidly as possible; and *Pierre Curie abandoned his work of crystals (provisionally, he thought)* to join me in search for the unknown element." *

Notice that the important preliminary observations, followed by the logical hypothesis, the key to the discovery of radium, were the work of Madame Curie alone. From now on months and months of toil were to be spent by husband and wife before the precious element, in the

* The italics are mine. See Marie Curie: *Pierre Curie* (1923).

form of a salt of radium, came into the hands of the workers. The source of the radium was an ore, pitchblende, and through the kindness of the Austrian government, which owned the extensive government mines in Joachimstahl, Bohemia, the Curies were presented with one ton of pitchblende from which the uranium had already been removed. Most of the common, and quite a number of the uncommon elements are present in pitchblende, so that the analytical procedure of separating one element from another, and examining each fraction so obtained, was a tedious and difficult one. The plan adopted by the Curies was to submit each fraction to electroscopic examination—a test based on Becquerel's method of detecting the presence of radium and similar rays by their action on a gold-leaf electroscope. The more active the fraction, the greater the effect on the electroscope. In this way a constant and invaluable check on the experiments was always at hand.

The large quantity of raw material made it necessary to conduct the initial experiments in a factory. The quantities were gradually narrowed down until the test tubes of the laboratory could hold them comfortably. The fraction containing the common element bismuth

showed the presence of a powerful radioactive substance, which, after many trials, was partially separated and named *polonium,* in honor of Madame Curie's native country. Further examination showed that the fraction containing the element barium had even more powerful radioactive properties; and by some of the most exhaustive and painstaking experiments in the history of the science, recalling those of Welsbach on the rare earths, Madame Curie succeeded in separating a salt of barium from a salt of the new element, to which she gave the name *radium.* Radium as an element baffled all attempts at isolation in the pure state until 1910, when our heroine solved this problem too; but even the salt of radium showed itself to be two and one-half million times as active as uranium!

The discovery of radium was first announced to the world in 1898, and by 1900 our immortal pair had already established its more important properties, among them the fact that here was an element the atoms of which were slowly breaking up, giving off, in so doing, enormous quantities of heat. The Great War produced no greater upheaval in the social and political structure of the world than did the discovery of radium in the world of science. Our concep-

tions of the constitution of matter, already attacked by Crookes, J. J. Thomson and others, now had to be thoroughly revised; and this involved not only the work of the scientist, but the speculations of the philosopher. It gave an amazing impetus to research in the physical sciences; so much so, that almost every great achievement in physics and chemistry since 1900 has its origin in the pioneer work of the Curies. It can be shown that even Einstein's topsy-turvy world is the indirect result of the discovery of radium.

The Nobel Prize, bestowed on the Curies in 1903, was a just recognition of the value of their work. In 1911, five years after her husband's death, Madame Curie was again awarded the Nobel Prize—this time given to her for her discoveries after 1903, and particularly for her successful isolation of the element radium in the pure state.

Turning our attention from the work to the woman and her husband, the story is one of struggle and self-sacrifice, of joy derived from doing the work you love, and joy derived from having your best friend share in it. We see the young girl, Marie Sklodowska, in her native city of Warsaw, studying mathematics and physics at college, joining the rebellious Polish

youth in their fight for a free Poland, and adding to her slender purse by hiring herself out as a governess. We meet her again, this time in Paris. She lives in a garret, six flights up. In the winter the room is cold, and there is never coal enough for the small stove. Marie prepares her own meals—bread, a cup of chocolate, eggs, perhaps a little fruit. But her life is wrapped up in her studies, and much of her life, therefore, appears far from intolerable. Then early in 1894 comes the touch of romance. She meets Pierre Curie, "a tall young man with auburn hair and limpid eyes. I noticed the grave and gentle expression of his face, as well as a certain abandon in his attitude, suggesting the dreamer absorbed in his reflections. We began a conversation which soon became friendly. It first concerned certain scientific matters about which I was very glad to ask his opinion. Then we discussed certain social and humanitarian subjects which interested us both. There was between his conception and mine, despite the difference between our native countries, a surprising kinship, no doubt attributable to a certain likeness in the moral atmosphere in which we were both raised by our families."

Pierre came again and again. They spoke

much about science, much about the social order. Common interests and healthy differences attracted them. At last comes a beautiful and almost passionate outburst from Pierre: "It would be a lovely thing in which I hardly dare believe, to pass through life together hypnotized in our dreams: your dream for your country; our dream for humanity; our dream for science. Of all these dreams I believe the last alone to be legitimate. I mean to say by this that we are powerless to change the social order. Even if this were not true, we should not know what to do. And in working without understanding we should never be sure that we are not doing more harm than good, by retarding some inevitable evolution. From the point of view of science, on the contrary, we can pretend to accomplish something. The territory here is more obvious and solid, and however small it is, it is truly in our possession."

Now there is no need in agreeing with Pierre (though I do—with much of it), but this quotation makes it evident that Pierre and Marie thought much, discussed many things, and the things discussed were not always science. If one is out to pick flaws in this lovely romance, it is that Pierre appears a little too sombre all the time; that the cause of humanity is never

for a moment separated from a more personal, selfish point of view; that you never hear the plain, ringing words of "You mean so much to me . . ." but rather the more philosophical outcry of a spirit touched by the world's problems: "Together we can serve humanity."

And so they married and worked together and struggled together—on a salary of 300 francs a month, "comparable to that of a day labourer"! And indeed not until shortly before Pierre's death, when he at length received a professorial appointment, did their financial situation improve. Radium they gave to the world, but the world gave them nothing distantly comparable in return. They took out no patents to protect their discovery, but freely gave their priceless material and the details of its preparation to the world at large. They were carrying out their pact, to serve humanity; and humanity took what they gave and thanked them in polite speeches and empty honours. Apparatus and equipment for the laboratory ate up the money obtained with the Nobel Prize. For years it was beyond the means of the pair to afford a servant, and Madame Curie had to occupy herself with the household and with the children, in addition to working in the laboratory—a laboratory which, much of the

time, was an abandoned shed, with a leaky roof, and devoid of hoods to carry away poisonous gases. It is not without a touch of bitterness that Madame Curie writes: "What reward does our society offer the scientist? Has he the means with which to work? Has he an assured existence, sheltered from care? The example of Pierre Curie, and of others, shows that he has none of these things; and that more often before he can secure possible working conditions, he has to exhaust his youth and power in daily anxieties. Our society, in which reigns an eager desire for luxury and riches, does not understand the value of science. It does not realize that science is a most precious part of its moral patrimony. Nor does it take sufficient cognizance of the fact that science is at the basis of all progress that lightens the burden of life and lessens its suffering. Neither public powers nor private generosity actually accord to science and to scientists the support and the subsidies indispensable to fully effective work." *

But the will to work was there, and the two worked and achieved despite all difficulties. In the spring of 1903 Pierre attended a dinner of the Physics Society. He sat next to Henri

* Marie Curie: *Pierre Curie* (1923).

Poincaré, the celebrated mathematician, and a brother of the former president and present January, 1927) premier of France. The two had much in common: they were scientists, they were dreamers, they were humanitarians. Pierre Curie came away from the table much inspired. The following day, on April 19, he attended a reunion of the Association of Professors. He left them and was crossing the Rue Dauphine when he was struck by a truck and fell under its wheels. A concussion of the brain brought instantaneous death. So ended one of the immortal pair. Happily for the world, Madame Curie survived the shock—by throwing herself even more intensively into her scientific work.

Radium gives off three types of rays, and these are distinguished by the Greek letters, α, β, γ. The α-rays have been shown to be atoms of helium which are thrown off with a velocity of about one-tenth that of light. That helium is one of the products obtained from radium has been shown by the work of Ramsay and Soddy.* Unlike the α-particles, which are charged with positive electricity, the β-particles are negatively charged ("electrons") and are shot out with a velocity equivalent to light.

* See my *Eminent Chemists* (1920), page 53.

They are identical with Crookes's "cathode" rays. A powerful magnetic field will bend the α-particles in one direction and the β-rays in the opposite direction. The magnet has no effect upon the γ-rays. These last are identical with the X-rays. The X-rays are further distinguished by their penetrating power. Whereas the α-rays are stopped by a sheet of paper or aluminum foil one-two-hundred-and-fiftieth of an inch in thickness, and the β-rays pass through gold-leaf or aluminum foil up to two-fifths of an inch in thickness, the α-rays penetrate thick layers of metals.

The stoppage of these various rays by the air molecules with which they come in contact generates much heat. One of the most remarkable things about this remarkable element is that the temperature around radium is about three degrees higher than the temperature beyond its immediate neighbourhood. To put this in another way, radium emits every hour enough heat to raise the temperature of its own weight of water from that of ice to that of boiling water. And what is more amazing still, its heat-generating power seems to be inexhaustible. The radioactivity of radium—and of thorium and uranium, though to a less degree—*is due to the breaking up of its atoms,* releasing

enormous quantities of energy which we recognize as heat.

If a radium salt is heated strongly, or dissolved in water and the water evaporated, the radium seems to show little radioactive power. If this residue be kept for a month, it can be shown to have recovered all its lost power. This experiment can be repeated indefinitely. If, now, the experiment is conducted a little more carefully, it can be shown that the initial loss of radioactivity is due to the escape of a gas which evolves the rays, in quality and quantity, that the residue has lost. This gas, or "emanation," was carefully examined by Ramsay and shown to be a new element, *niton*, belonging to the inert gases of the atmosphere, of which helium is the most popular member. The further interesting fact was brought out that on standing the "emanation" loses its radioactive power, and its rate of loss is strictly proportional to the rate of gain in radioactive power of the radium residue. Radium breaks up into two elements, niton and helium; the niton breaks up still further into a simpler element, and also gives off an atom of helium. The process has been traced experimentally through quite a number of stages, and the peculiar feature of this "disintegration" process

is that at each step an atom of helium is set free. Why just helium? The following chapters may throw some light on the question.*

* For further reading on the subject—the inexhaustible subject—of radium and all that it implies, consult F. Soddy: *Matter and Energy* (1912); F. Soddy: *The Chemistry of the Radio-Elements* (1914); and E. Rutherford: *Radioactive Substances and Their Radiations* (1913).

CHAPTER VIII

THE ATOM: THE ENERGY OF THE FUTURE

PARTICULAR attention is now being given by scientists to three new sources of energy. These are solar energy, the internal heat of the earth, and atomic disintegration, or the breaking up of the atoms. Let us briefly consider the first two types of energy before taking up the third type.

We are all familiar with the fact that plants, in the course of their synthetic work, make use of energy obtained from the sun; but as a matter of fact, not more than one-three-hundredth of the available supply is used in this way. Much of the rest ought to be more profitably utilized than it is at present. But how?

To begin with, we must find a means of storing up this energy, this solar energy, in much larger quantities than nature does at present. We must force the hand of nature by imitating her and by surpassing her. The plant takes in moisture and carbon dioxide from the air, and, with the help of its chlorophyll, of solar energy,

of the nitrates and other mineral salts in the soil, builds itself up. But this building process takes much time. Can we not accelerate such a reaction? Perhaps.

The velocity of all chemical reactions can be changed by changing the conditions surrounding such reactions. You may increase the velocity by increasing the temperature, or by introducing another substance (a "catalyst"), or by increasing the pressure. Increasing the temperature surrounding the plant must be ruled out because of the too delicate response to temperature changes of protoplasmic material: protoplasm is too easily destroyed by a relatively slight increase in temperature. Increasing the pressure holds out much brighter prospects, according to Professor Kreusler, who has carried out extensive researches along these lines. There is no reason why the amount of carbon dioxide cannot be increased tenfold by introducing the gas at a pressure of ten atmospheres. This might mean a rate of growth ten times as fast as the average of to-day. And catalyzers of the chlorophyll type—substances that accelerate reactions by their mere presence —can also be found to hasten the work.

For the purpose in hand the types of the plant produced are of little importance: they

may be herbs or they may be trees. What is essential is that whatever grows should grow fast, and the combustible material so formed can be burned as soon as it has reached maturity.

The idea here outlined was sponsored by the late Professor Ciamician, of the University of Bologna, world-renowned for his researches in photo-chemistry. He pictures much of the harvest of the future to be one which, dried by the sun, will be converted into gaseous fuel; and the latter will be burnt on the spot in gas engines, thereby generating mechanical energy which can be transmitted elsewhere. The ammonia and carbon dioxide, by-products in such a reaction, and the ashes that are left after burning the fuel, can furnish the raw materials necessary for the next harvest. This paves the way for a continuous cycle of operations.

With reference to making use of the internal heat of the earth, it is a matter of common knowledge that the temperature of the earth increases towards its interior, and the suggestion of utilizing this heat has often been made. At first sight this source of energy appears most promising. At certain points of the earth's surface, notably in the Yellowstone Park, in Iceland, and in the northern districts

of New Zealand, abundance of water at a temperature of 200 degrees Fahrenheit is brought to the surface by hot springs and geysers. In such places there is no reason why this temperature should not be utilized in working a steam plant. To utilize the earth's internal heat at any other point of its surface, it would be necessary to sink holes to a depth sufficiently great to enable the required high temperature to be attained. Sir Charles Parsons, the distinguished English engineer, has discussed the question of sinking a shaft to a depth of twelve miles, which is about ten times the depth of any shaft in existence. The estimated cost would be $25,000,000, and the time required about eighty-five years.*

Finally we have atomic energy. As has already been pointed out, Madame Curie's discovery of radium has led to the observation that the atoms of that element are in constant process of breaking up, in the course of which large quantities of energy, in the form of heat, are liberated. The temperature of the air surrounding a piece of radium is about three degrees higher than the temperature beyond its

* See A. H. Gibson: *Natural Sources of Energy* (1913); Svante Arrhenius: *Chemistry in Modern Life* (1925), page 160; and Sir Charles Parsons's article in *Contemporary Science* (1921, page 43) by Benjamin Harrow.

vicinity. It continues to give off such heat for years without any appreciable loss. Indeed, calculation shows that it would take 2,500 years for a piece of radium to liberate the total energy stored in it. While, therefore, the heat given off in any minute is relatively small, the total heat evolved over so many years is enormous. It is 250,000 times as much as can be obtained from an equal weight of coal when burnt.

The problem before us, in so far as radium is concerned, is this: We must so change conditions that the small amount of heat given off during hundreds of years may be changed into large quantities of heat given off in a much shorter interval of time. So far all our attempts to do this have failed. But even were a method found of accelerating the rate of radioactive transformation, our problem would still remain unsolved; for the total quantity of available radium is small, and only two other elements besides radium, thorium and uranium, show any evidence that their atoms are disintegrating.

What we need to find is a method of breaking up the atoms of elements more abundant in nature than radium—iron, copper, lead, tin, zinc, etc.; which means that we have to discover the method adopted by nature of breaking up the

atoms of radium. Some experiments performed by Sir William Ramsay several years ago seemed to hold out hope in this direction, but a repetition of these experiments by Madame Curie failed to substantiate Ramsay's claims. Sir Ernest Rutherford is now attacking the problem, and though the work is still in its embryonic stage, the results so far are highly promising.

CHAPTER IX

THE ATOM: ITS STRUCTURE

THE electron, to which we have already referred, represents a negative particle of electricity. Where is the positive particle? The atom itself is electrically neutral, so that when, by decomposing it, you get a negatively charged particle, it is reasonable to assume that what remains must be of the opposite charge. We have already seen that when a tube containing air, or hydrogen, or any other gas, is evacuated, and a current passed through, electrons issue from the cathode. The cathode being the negative pole *repels* the electrons, which are negatively charged particles. On the other hand, the cathode ought to *attract* positively charged particles, since like and unlike electricities attract one another. Goldstein, in fact, as early as 1896, using a perforated cathode, showed that cones of violet light projected from the holes *behind* the cathode. These "canal" rays, as they were called by their discoverer, were next subjected by Wien to an analysis

similar to the analysis of the electron by Thomson, with these results: The "rays" could be deflected by magnetic and electric forces, just as the electrons, but the *deflection was in the opposite direction.* Clearly, then, these rays represented the positive particles. Further, an estimation of their mass showed that these particles (which have since received the name of "protons") were much, much heavier than the electrons; that, indeed, the proton weighed about as much as a hydrogen atom; which meant that the proton was about 1700 times as heavy as the electron. The English school of physicists, among whom must be mentioned Thomson, Rutherford and Aston, are mainly responsible for the remarkable development, in our own day, of *positive* ray analysis—an analysis which has thrown a flood of light on the "nucleus" or inner structure of the atom.*

The "nucleus" of the atom is the discovery of Rutherford (1871 —) and upon it is based his theory of the structure of the atom. Studies in radioactivity and an examination of its rays led to these important results: the constant and relatively enormous amount of heat generated by radium could result only from the breaking

* See J. J. Thomson: *Rays of Positive Electricity* (1921); and F. W. Aston: *Isotopes* (1922).

up of the atom itself and involves changes quite different from the chemical changes with which we are familiar. This led to the supposition that when one atom unites with another in chemical combination, involving heat changes which in amount are infinitesimal compared with those obtained in radioactivity, only the surfaces of the atoms are scratched, so to speak, the inner parts remaining intact; but in radium Nature exhibits an element whose inner parts are disturbed. We must then postulate that there are two distinct parts to an atom: an inner, relatively stable part, the "nucleus," and an outer, less stable part, the "planetary circle."

Here we have the germ of the nuclear theory of the atom, as enunciated by Rutherford. But it must also be added that this prince among physicists—who has recently been elected to the presidency of the Royal Society—had produced some very convincing experimental evidence not only to justify his nuclear theory, but actually to estimate the size of the nucleus. The evidence depends upon the passage of alpha particles, obtained from radium, through various atoms. These particles, as a rule, shoot through atoms without deviating from their path, showing that there are no material bodies

in their way; but sometimes their direction is deflected—there is a rebound; and then it becomes clear that the *alpha* particles have struck a body. This body is part of the "nucleus" or "sun" of the atom. Since from the "nucleus" of radium we get both *alpha* and *beta* particles, and since analysis shows that these *alpha* particles are positively charged atoms of helium, and the *beta* particles are electrons, or negatively charged particles; and since, furthermore, the positive charges in the nucleus are greater than the negative charges; it is assumed that the "nucleus" of the atom consists of positive and negative electricity, with the former preponderating. The atom as a whole is neutral. It is neutral because the nucleus of the atom has a positive charge (due to the preponderance of positive over negative charges), and this "nucleus" or "sun" is surrounded by satellites—electrons in this case—which are negatively charged, with a total charge equal but opposite to that on the nucleus. So that we arrive at the remarkable conclusion that the atom, the chemist's simplest piece of matter, is a combination of positive and negative electricity, and matter is really electrical in origin.

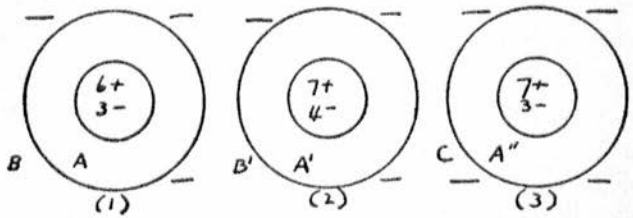
But Rutherford has not stopped here. He has submitted the "nucleus" to even closer ex-

amination. He has shown, by an extension of his *alpha*-ray attack on atoms, that the diameter of the "nucleus" is very, very small as compared to the diameter of an atom itself; though practically the entire weight of the atom is centred in the "nucleus." And, to crown an achievement of glorious feats, by a violent bombardment of the nitrogen atom with *alpha* rays, he has actually obtained helium and hydrogen. Nitrogen, helium and hydrogen have always been held up by the chemist as typical examples of elements—of substances which cannot be further decomposed. Why, then, should we get hydrogen and helium from nitrogen? The answer is not a difficult one. The atoms of hydrogen are the lightest known, and the atoms of helium, though heavier than the hydrogen atoms, are lighter than the atoms of any other element. It is therefore probable that the atoms of nitrogen represent suitable combinations of the atoms of hydrogen and helium. A number of atoms other than nitrogen, whose atoms are all heavier than the atoms of hydrogen and helium, have yielded these two gases when subjected to *alpha*-ray bombardment; so that we seem justified in stating that hydrogen and helium represent an early stage in the evolution of the elements.

Rutherford's conception of the structure of the atom as a solar system in miniature has given us a somewhat deeper insight into the meaning of chemical and radioactive changes. Perhaps nothing was so striking in connection with the discovery of radium as that the radioactive rays which it emits could not be controlled by any means known to man. Neither the highest nor the lowest temperatures will accelerate or retard a radioactive change. You can put radium in the electric arc or you can put it in liquid air without in the least affecting the rate of the rays given off by the element. Such a change is quite different from any chemical change which has been studied. Every chemical reaction is influenced by temperature, being accelerated when the temperature is increased and retarded when it is decreased; so that in liquid helium, where we approach the absolute zero, combinations between elements practically cease, and in Moissan's electric arc furnace, registering 6,000 degrees Fahrenheit, all kinds of refractory elements are made to combine. Why cannot radioactive changes be similarly controlled? Because—and this has been touched upon before—a radioactive transformation is really a fundamentally different thing from a chemical one. In the latter, only the

planetary electrons are affected; the "nucleus" is not touched. A radioactive change is due to a disturbance of the "nucleus." When atoms of hydrogen, for example, combine with atoms of oxygen to form water, only the planetary electrons of these atoms are affected; but when radium spontaneously decomposes, it is because the "nucleus" is undergoing decomposition.

To pave the way for the next advance, allusion will be made to the two simple diagrams illustrated in Figures (1) and (2). In (2) is represented in an extremely crude form an



imaginary atom of an element whose "nucleus" consists of 7 positive and 4 negative particles, as compared to 6 positive and 3 negative particles in the atom represented in (1). In both atoms the excess positive over negative charges is three, so that to neutralize these we shall require three electrons around each of the planetary systems: three around B and three around B′. The chemical properties of the

atom—and therefore the element consisting of millions of such atoms—depend upon the number of electrons around B or B′. Since these are the same in our example, the chemical properties of these elements must be the same. But you will please remember the evidence brought forward by Rutherford to the effect that the weight of the atom is almost entirely centred in the positive charge, or proton. Since there are 6 such charges in (1) and 7 in (2), there ought to be an appreciable difference in weight between these two atoms. These atoms illustrate an example of *isotopes* (a word coined by Professor Soddy, of Oxford, who is responsible for much of the work on isotopes)—elements having the same chemical properties but different atomic weights. Our own Professor Richards, of Harvard, first showed that lead obtained from radioactive sources has an appreciably lower atomic weight than lead obtained from ordinary lead ores, though the most refined chemical analysis failed to detect any other difference between these two varieties of lead. Here you have an example of isotopes.

Aston, working in Rutherford's laboratory in Cambridge, has been able to demonstrate that many of the common elements are really *mixtures* of two or more isotopic modifications, one

modification differing from the other by a slight difference in weight only, but otherwise, in chemical and spectroscopic behaviour, quite indistinguishable; which explains why the existence of isotopes was quite unknown until recently. Aston's method of analysis does not make use of the balance at all: the differences in weight are often so small that not the most delicate balance will detect them; it is in reality an extension of Thomson and Rutherford's positive ray analysis, depending upon the separation of the positive from the negative charges of the atom, and analyzing the former when under the influence of magnetic and electrical forces. Since isotopes merely differ in density, and since practically all the weight resides in the positive charges, an analysis of the latter, involving, among other things, their velocity, is sufficient to bring out essential differences (using several mathematical principles).*

The study of isotopes gives a new meaning to the word "element." Until isotopes were discovered, mercury, for example, was considered an element—a substance that could not be divided into anything simpler. Aston, however, has shown that mercury is a mixture of no less than *six* different isotopes. What are we to

* See F. W. Aston: *Isotopes* (1922).

Frederick Soddy

Soddy, active worker in the field of radiochemistry (p. 81)

T. W. Richards

Richards, professor of chemistry at Harvard, well-known for his atomic weight determinations (p. 81)

do? Are we to designate each isotope of mercury an element, and refer to ordinary mercury as a mixture? "If we adopt this view," writes Aston, "a new word will be necessary to express such substances as chlorine or magnesium or mercury, hitherto called elements, and also the word element would mean something entirely different from what it has meant in all the chemical and physical literature of the past century. It would moreover be still subject to alterations. . . . Let us fix the word precisely, now and for the future, as meaning a substance with definite chemical and spectroscopic properties which may or may not be a mixture of isotopes—in other words, to associate it exclusively with the conception of atomic number." How vastly different is this conception of the elements from that of the Greeks with their earth, air, fire and water!

If we refer again to the figures we may recognize still another possibility. Suppose the nucleus of figure (3) to consist of 7 positive and 3 negative charges. This would give an excess of 4 positive charges, and therefore 4 electrons around C would be necessary to neutralize them. The atom represented by (2) would require but 3 outer electrons. Since the number of outer electrons in (2) and (3) would differ,

and since the chemical properties of the element depend upon these outer electrons, the two elements would exhibit different chemical properties. Since, however, they both have the same total number of positive charges, and since the weight of the atom is practically the weight of these charges, the two elements would have the same atomic weight. Elements with the same atomic weight but different chemical properties are *isobares,* as distinguished from isotopes, where we deal with elements having different atomic weights but the same chemical properties. Rutherford and Soddy, in their studies of the disintegration of the radium series of elements, have shown how isotopes and isobares may be formed.*

The excess positive over negative charges in the nucleus—at A and A′ and A″—is called the *atomic number;* so that the atoms in (1) and (2) have an atomic number of 3 and the atom in (3) has an atomic number of 4. These atomic numbers are considered as perhaps the most fundamental characteristics of the elements. Using the X-ray spectra of the elements (which differ with different elements and which can be obtained by bombarding the elements with *beta*

* See F. Soddy: *The Chemistry of the Radio-Elements* (1914).

rays or electrons), Moseley, an Englishman twenty-six years old, working in the Cavendish Laboratory in Cambridge just before the outbreak of the War, showed how the atomic number for every known element can be calculated. If the atomic number of hydrogen, the lightest element, be called one, that of helium, the lightest but one, is shown by calculation to be 2, the next, lithium, 3, and so on (4, 5, 6, 7, 8, etc.), until the heaviest element, uranium, is reached, which has an atomic number of 92. That such a "flight of stairs with perfectly definite, even treads" is obtained, makes it evident that Moseley's discovery touches the very root of ultimate reality in the material world.

Moseley, with probably one or two other budding Einsteins and Rutherfords, was killed in the Great War. "Had the European war had no other result than the snuffing out of this young life," writes Professor Millikan, "that alone would make it the most hideous and most irreparable crime in history."

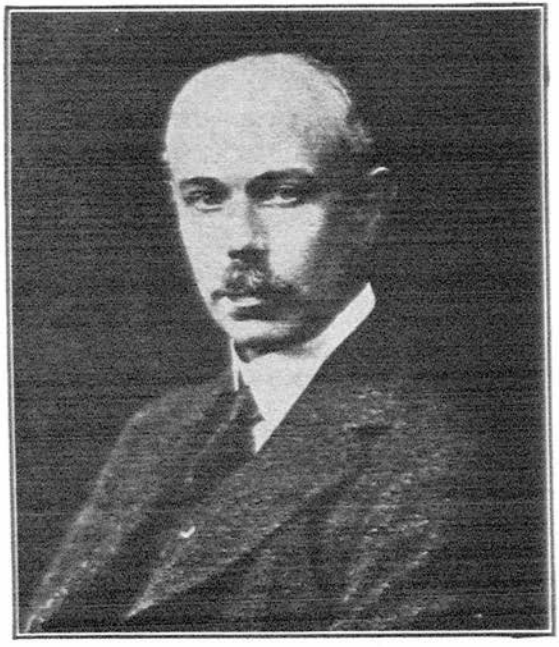
At about the same time when Moseley was engaged on his atomic numbers, Niels Bohr, a young Dane, who was working in Rutherford's laboratory, took up the latter's theory of the structure of the atom and has since extended

it a great deal, showing, among other things, that the characteristic spectra yielded by elements (upon which is based the whole science of spectrum analysis) is related to different stable orbits around the nucleus of the atom. But his theory in its complexity rivals Einstein's, and we must leave it here.

And so our journey comes to an end—for the time being. Our inn is the electron. The Rutherfords, the Millikans, the Astons, the Bohrs are recuperating there. They and their disciples will take up the trail again. It may lead to the discovery that the very electron is no less a miniature solar system than is the atom itself. Why not? Why a limit to any number, whether large or small? Why suppose that either this age, or the next, or any age will ever reach finality in any one direction? So we play with Einstein and his fourth dimension, already figuring that there may be a fifth and a sixth. And so we play with Rutherford and his electron, ready to bounce upon Mr. X, the parent of all the electrons. What a game for the mind! What an uplift for the soul! How utterly incomprehensible that the creature of God who dives into the atom and brings to the surface divine specks of beauty and truth is the same

MOSELEY

Moseley, to whom we are indebted for our knowledge of atomic numbers (p. 85)



ASTON

Aston, a brilliant experimental worker in the field of isotopes (p. 82)

creature who dives into hell and brings about the Great War! *

* A very comprehensive, but technical, book dealing with the atom is E. N. da C. Andrade's *The Structure of the Atom* (1923). Other works of merit, some more, some less technical are O. W. Richardson: *The Electron Theory of Matter* (1916); J. Cox: *Beyond the Atom* (1913); Bertrand Russell: *The A. B. C. of the Atoms* (1923); John Mills: *Within the Atom* (1921); and Sir Oliver Lodge: *Atoms and Rays* (1924).

CHAPTER X

AN APPLICATION OF THE STRUCTURE OF THE ATOM: THE WORK OF RAYLEIGH AND RAMSAY

SALT is found in the ocean and in the bowels of the earth. The earth's deposits are merely prehistoric remains of ocean deposits, so that sea water may be regarded as the mother substance of salt. Since the ocean covers three-fourths of the earth's surface to an average depth of three miles, and since the per cent of salt in the ocean is 2.8, the amount of salt in the ocean, if isolated, would be enough to cover six million cubic miles of space.*

Industrially, salt is of enormous importance. The preparation of chlorine, of muriatic acid, of bicarbonate of soda and washing soda, all require salt. Physiologically, it is an indispensable article of food. Out of it the necessary muriatic acid (or hydrochloric acid, as the chemist prefers to call it) in the stomach is formed. With its help equilibrium conditions are set up between the cells and the solutions

* See H. G. Deming: *General Chemistry* (1925).

which bathe them—conditions quite vital for the efficient functioning of the organism.

The chemical name for salt is sodium chloride, a name which suggests that the substance is made up of sodium and chlorine. And indeed, an analysis of pure sodium chloride, irrespective of its origin, always shows it to contain sodium and chlorine, and nothing but these elements. Now when we investigate the properties of sodium and chlorine, and compare them with the properties of sodium chloride, we find not only striking differences among the two elements themselves, but among the two elements on the one hand, and the substance which is composed of these two elements. Sodium, for example, is a highly poisonous and extremely active metal; so active, that merely bringing it in contact with water causes a violent reaction. Chlorine shares honours with sodium in being poisonous—it is the parent of all the poison gases used in the late war—but, unlike the latter, is a gas. Sodium chloride is not only a harmless solid, but an indispensable article of food. In a way, there are few more impressive chemical experiments, if the philosophical consequences be weighed, than the experiment in which a burning piece of sodium is plunged into chlorine gas, with the resultant

formation of common salt. Here we have an example, *par excellence*, of chemical action, in which two elements unite to form a compound widely differing in physical and chemical properties from the elements out of which it was formed.

If now we ask, just what has happened in this reaction? what is this chemical action? we must seek our answer by examining the atomic structure of the elements as it has been revealed to us during the last ten years; and, more particularly, by examining the work of a distinguished American chemist, Langmuir. We shall see that in the place of the very vague and rather glib answer of the chemists of a former generation, that the forces of "chemical affinity" are at work, we can offer a hypothesis which brings us one step nearer to ultimate reality.

We must retrace our steps somewhat and dwell on a discovery of far-reaching importance which is due to Lord Rayleigh and Sir William Ramsay, and which was given to the world in 1894.

The Hon. William Strutt, third Baron Rayleigh (1843-1919), is best remembered for his discovery of argon, a gas present to the extent of about one per cent in the air we breathe.

During his life of seventy-seven years, however, he published a *Theory of Sound*, which is the most scholarly treatise of its kind in the English language, and more than four hundred original contributions to physics. He was the friend and intimate of Clerk Maxwell, Kelvin and Helmholtz; and his reputation suffers only by comparison with these three giants. He succeeded Clerk Maxwell as Cavendish Professor of Physics at Cambridge, and was in turn succeeded by J. J. Thomson. Here again Lord Rayleigh suffers by comparison: Rayleigh was a great physicist, but Clerk Maxwell and J. J. Thomson were still greater ones.

When at twenty-three Rayleigh graduated from Cambridge as Senior Wrangler, a clerical relative urged on him the claims of "duty," by which was to be understood the normal public duties of a country squire or of a cabinet minister. Rayleigh replied that he owed his "duty" to science; whereupon the clerical relative said something to the effect that to neglect the estate and state in order to follow scientific pursuits was a lapse from the straight and narrow path.* The clergyman's opinion of science was evidently shared by the authori-

* See *The Life of Lord Rayleigh* by his son, Lord Rayleigh (1924).

ties at Cambridge, for at that time—in 1867—the only experimental course offered at the university was one in qualitative analysis—"test-tubing," as it is lovingly called by the undergraduates of to-day. From 1867 to 1926 is a far cry. The Cavendish Laboratory for Experimental Physics is the most famous of its kind the world over. On any week-day you may find three Nobel prize winners, Thomson, Rutherford and Aston, at work there. Even so specialized a field as bio-chemistry boasts of a building all its own. At Cambridge the blackboards are still filled with mathematical symbols as they were in Newton's day; but now largely as a preliminary means of developing some hypothesis to be tested out in the laboratory. When Einstein develops a theory dealing with the refraction of light rays as they pass the sun, it is the Cambridge astronomer, Eddington, who verifies it experimentally. When Thomson develops his theory of the structure of the atom, it is Wilson, a Cambridge physicist, who devises an ingenious experiment to photograph the track of *alpha* rays as they shoot out of radium.

Rayleigh at twenty-four was elected a Fellow of Trinity College. He was excellently equipped in mathematics, but knew little or

nothing of laboratory work. Being a man of means, he set up his own laboratory, hired his own assistant, read Maxwell's papers on the electro-magnetic field, Helmholtz's on colour vision, and the chief publications of Stokes and Kelvin. These gave him the necessary impetus for experimental work, which he carried on unintermittently and unobtrusively for a quarter of a century.

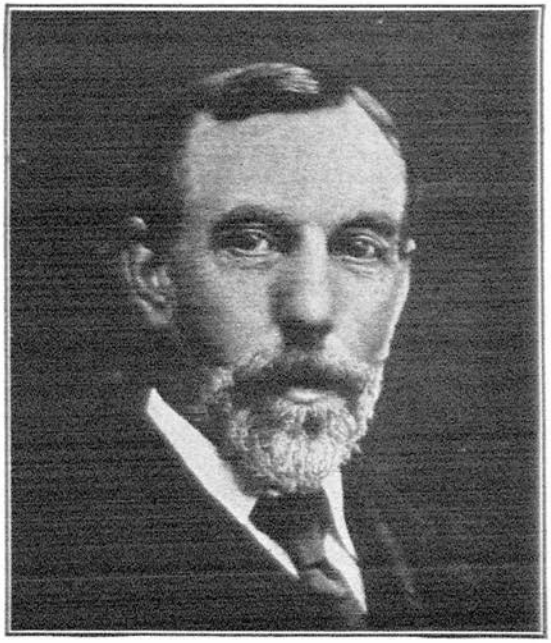
The turning point in his career came in 1894. An apparently inconsequential series of determinations dealing with the densities of gases led to a momentous discovery—argon, a hitherto undiscovered gas in the atmosphere; and subsequently to the unmasking of four other elementary gases in the air: helium, neon, xenon and krypton. In his experiments Rayleigh found that the density of nitrogen obtained from the air was slightly but consistently higher than that obtained from artificial sources. Writing to *Nature,* he said: "I am much puzzled by some results as to the density of nitrogen and shall be obliged if any of your chemical readers can offer suggestions as to the cause. According to two methods of preparation I obtain quite distinct values. The relative difference, amounting to about one-one-thou-

sandth part, is small in itself; but it lies entirely outside the errors of experiment."

Rayleigh's letter to *Nature* attracted the attention of Ramsay (1852-1916), professor of chemistry at the University of London. The London chemist had found that nitrogen is absorbed fairly readily by magnesium. This suggested to him that by first getting rid of the oxygen in the air and passing the remaining nitrogen over heated magnesium, any other gas that might be present in the atmosphere would not be absorbed. The experiments fully confirmed the hypothesis, and the unabsorbed gas was isolated.* In the meantime, Rayleigh himself had arrived at the same result, using different means. He had repeated and extended an almost forgotten experiment of Cavendish, performed one hundred years earlier. Rayleigh and Ramsay joined hands; they announced their discovery to the British Association for the Advancement of Science which met in the summer of 1894.

The scientists were skeptical. What! Could it be possible that the atmosphere so exhaustively studied by scientists for centuries contained a gas which had never before been isolated! They shook their heads, smiled the

* See W. A. Tilden: *Sir William Ramsay* (1918).



W. Ramsay.

Ramsay, discoverer of gases in the atmosphere (p. 94)

Rayleigh

Rayleigh, one of the discoverers of argon (p. 90)

smile of doubters, spoke of faulty manipulation and hasty conclusion, and suggested more caution and less eagerness to rush into print. Ten years later, in 1904, Rayleigh received the Nobel Prize for physics and Ramsay the corresponding prize for chemistry.

Now by far the most remarkable property of this gas, this argon, is that, chemically, it is wholly inert (hence the name *argon,* inactive). Ramsay and Rayleigh tried every means in their power to make this element combine with some other element or compound, but to no purpose. Not so long before the discovery of argon, Moissan at the Sorbonne had for the first time isolated fluorine, the most active of elements; so active, that for years no one had been able to separate it from its compounds. Yet this same fluorine did refuse to combine with argon.

Soon after the discovery of argon, Ramsay's attention was called to some experiments of Hillebrand, of the U. S. Geological Survey, in which he obtained a gas believed to be nitrogen from certain minerals, particularly a mineral called clevite, but which was now suspected to contain argon as well. Ramsay lost no time. From it he obtained argon, to be sure, but also another gas, with a spectrum all its

own, which showed it to be identical with an element present in the chromosphere of the sun, and which until then had been considered peculiar to the sun. Lockyer years ago had given the name "helium" to it, and now Ramsay had rediscovered it on the earth. But let the discoverer tell the exciting news. On the 24th of March, 1895, he writes to his wife: "Let's take the biggest piece of news first. I bottled the new gas in a vacuum tube, and arranged so that I could see its spectrum and that of argon in the same spectroscope at the same time. There is argon in the gas; but there was a magnificent yellow line, brilliantly bright, not coincident with but very close to the sodium line. I was puzzled, but began to smell a rat. I told Crookes [Sir William Crookes, to whom we have already referred], and on Saturday morning when Harley, Shields [his two assistants] and I were looking at the spectrum in the dark room a telegram came from Crookes. He had sent a copy here and I enclose that copy. You may wonder what it means. Helium is the name given to a line in the solar spectrum, known to belong to an element, but that element has hitherto been unknown on earth. It is quite overwhelming and beats argon. I telegraphed to Berthelot [a fa-

mous French chemist] at once yesterday—'Gaz obtenu par moi clevite mélange argon helium. Crookes identifié spectre. Faites communication Académie lundi.—Ramsay.' . . . I have written to Lord Rayleigh and I'll send a note to the R. S. [Royal Society] to-morrow. . . ."

The first public account of helium was given to a semi-bewildered audience at the annual meeting of the Chemical Society, in 1895, on the occasion of the presentation of the Faraday Medal to Lord Rayleigh. Further investigations proved that helium was not only a terrestrial element, but also occurred in quite a number of minerals and mineral waters. To Kayser, however, was left the proof of its presence in the air. Like argon it simply refused to combine with any other substance.

Till 1894 no one, least of all a scientist, would have suspected the existence in the atmosphere of undiscovered elements.* Ramsay and Rayleigh's discovery shook the scientific world. Recognition came from all parts. Lord Kelvin, as President of the Royal Society, presented Ramsay with the Davy Medal, with the following comment:

". . . The researches on which the award of the Davy Medal to Professor Ramsay is

* Cavendish, in 1785, did suspect some such possibility.

chiefly founded are, firstly, those which he has carried on, in conjunction with Lord Rayleigh, in the investigation of the properties of argon, and in the discovery of improved and rapid methods of getting it from the atmosphere; and secondly, the discovery in certain rare minerals, of a new elementary gas which appears to be identical with the hitherto hypothetical solar element, to which Mr. Lockyer many years ago gave the name of 'helium.' . . . The conferring of the Davy Medal on Professor Ramsay is a crowning act of recognition of his work on argon and helium which has already been recognized as worthy of honour by scientific societies in other countries. For his discoveries of these gases he has already been awarded the Foreign Membership of the Société Philosophique de Genève and of the Leyden Philosophical Society. He has had the Barnard Medal of Columbia College awarded him by the American Academy of Sciences, and within the last few weeks he has been elected a Foreign Correspondent of the French Académie des Sciences."

Such was the excitement aroused by these discoveries that even young students were filled with the epidemic. We are told that "answers to examination questions showed that oxygen

as a constituent of the air was almost forgotten in the anxiety on the part of the candidate to show that he or she knew all about argon." But Ramsay had not yet sufficiently dumbfounded his scientific colleagues. From a careful study of Mendeléeff's periodic grouping of the elements, he came to the conclusion that another inert gas ought to exist between helium and argon, employing a process of reasoning quite analogous to that used by the celebrated Russian many years before when, with the help of the periodic table, Mendeléeff predicted the discovery of new elements. Ramsay ransacked every possible source for this new element: minerals from all parts of the globe, mineral waters from Britain, France and Iceland; meteorites from interstellar space—all without result. A clue was at length obtained when he found that by diffusion argon could be separated into a lighter and a heavier portion. This suggested the presence of the unknown gas as an impurity mixed with argon. It was evident that the unknown gas, if present, could be there in minute quantities only to have escaped detection. That meant that the larger the quantity of argon employed the better the possibilities of getting appreciable quantities of the unknown constituent.

A simple method of separating the constituents in a mixture is to boil the mixture and collect fractions of the condensed vapour. Each constituent will usually go off at a fairly definite temperature. This, in principle, was the method employed by Ramsay and his assistant, Travers. They prepared, to begin with, no less than fifteen litres of *liquid* argon. "On distilling liquid argon," writes Ramsay, "the first portions of the gas to boil off were found to be lighter than argon; and on allowing the liquid air to boil off slowly, heavier gases came off at last. It was easy to recognize these gases by help of the spectroscope, for the light gas, to which we gave the name *neon* or the 'new one,' when electrically excited emits a brilliant flame-coloured light; and one of the heavy gases, which we called *krypton* or the 'hidden one,' is characterized by two brilliant lines, one in the yellow and one in the green part of the spectrum. The third gas, named *xenon* or the 'stranger,' gives out a greenish-blue light, and is remarkable for a very complex spectrum in which blue lines are conspicuous."

A trio, neon, xenon, krypton, added to helium and argon—making five new gases in all—and all in the atmosphere! Further recognition came from the Chemical Society of Lon-

don. They awarded Ramsay the Longstaff Medal, given triennially to the Fellow of the Chemical Society who, in the opinion of the Council, has done the most to promote chemical science by research. "If I may say a word of disparagement," said Mr. Vernon Harcourt, the president, in presenting the medal, "it is" —and here we can see the twinkle in his eye— "that these elements (argon, helium, etc.) are hardly worthy of the position in which they are placed. If other elements were of the same unsociable character chemistry would not exist." *

* See Benjamin Harrow: *Eminent Chemists of Our Time* (1927); also, W. A. Tilden: *Sir William Ramsay* (1918). Mr. Harcourt, of course, alluded to the fact that these five gases cannot be made to combine with any element or compound. Within the last few days (August, 1926) an English chemist has announced to a British Association audience that he has succeeded in causing helium to combine with mercury. If this experiment is confirmed, we shall have to revise our view as to the complete "inertness" of these elements.

CHAPTER XI

AN APPLICATION OF THE STRUCTURE OF THE ATOM: THE WORK OF LANGMUIR

EXCEPT for the fact that the "inert" gases (argon, helium, etc.) varied in density, these elements were all alike in one respect: they refused to enter into any kind of chemical combination. With an intuition which is the gift of genius only, Irving Langmuir (1881 —), the American chemist, drew from these observations one conclusion of far-reaching consequence: these elements are inert, he said, because they have "stable systems"; because the configuration of their atoms is of such a nature as to give us maximum stability and a minimum desire on their part to enter into chemical combination.*

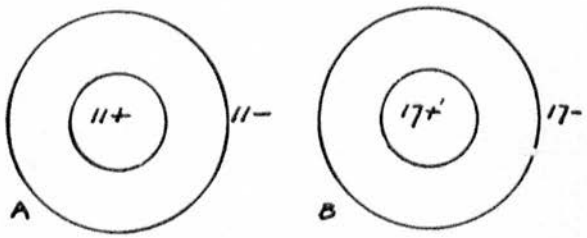
* It should be added, in fairness, that Kossel in Germany and Lewis in this country had already advanced some such idea, but we owe to Langmuir the first clear statement and logical development of the theory. (See G. N. Lewis: "The Atom and the Molecule" in the *Journal of the American Chemical Society*, volume 38, page 762, 1916.) However, Lewis, in many respects, shares honours with Langmuir in developing the theory discussed in this chapter.

But granted that the configuration is a stable one, how are we to picture such a configuration? Here Langmuir had to wait until Thomson, Rutherford and others had developed their theory of the structure of the atom; and, more particularly, until Moseley made his discovery of atomic numbers.

Without going into details, which do not concern us here, let us extract from Rutherford's theories those portions which are of value to us in our present exposition. The atom consists of a nucleus of positive and negative charges of electricity, called protons and electrons, respectively, in which the protons predominate. Practically the entire weight of the atom is dependent upon the number of protons present. Surrounding the nucleus is a miniature solar system of electrons, equal in number to the excess protons in the nucleus; so that the atom as a whole is neutral. Chemical changes involve the outer circle of electrons, never the nucleus. Only in radioactive changes is the nucleus involved. The essential difference between the atoms of different elements is a difference in the number and arrangement of the outer electrons.

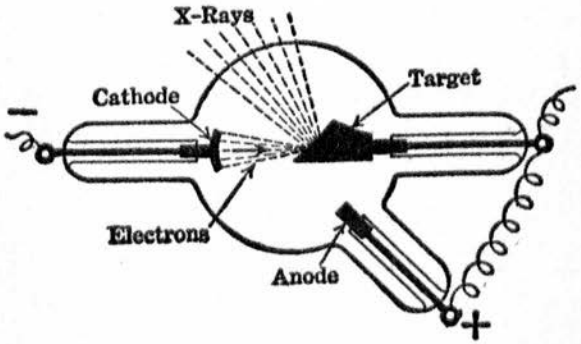
To make these statements clearer, let us illus-

trate with an example which will help us in understanding the theory, though the diagrams are not to be taken as representing the exact configuration of the atoms. Suppose I have an atom of element A with an excess of 11 protons in the nucleus and another of element B with an excess of 17 protons in the nucleus; then I may represent A and B as



the —11 in the outer circle of A, and the —17 in the outer circle of B representing the number of electrons necessary to neutralize the excess protons in the nuclei of A and B respectively; so that the atom as a whole is electrically neutral. The chemical differences of the atoms A and B depend upon the difference in the number of the outer electrons (11 and 17) and upon their distribution. But at this point the reader may well ask, How do we know how many electrons there are in the outer circle? and how do

we know how these electrons are distributed? In answer to the first question, it is obvious that if we can determine the excess number of positive charges on the nucleus, we immediately get the number of electrons in the outer sphere; for the number in each case is the same, except that in the one case we have positive particles of electricity, or protons, and in the other, nega-



[From Deming's *General Chemistry*]

tive particles of electricity, or electrons. We owe to Moseley, a young Englishman, the solution of this problem. His work involves the X-ray tube, and we shall discuss this first.

By exhausting the air in a tube of the shape shown in the diagram, a current of electricity can be forced through the apparatus. From the

cathode, or the negatively charged pole, there shoots out a stream of negatively charged particles, or electrons, which are made to fall on a metallic target. (In the radio detector and in amplifying bulbs we have electrons flying off the filament.) The target gives off heat, light —and X-rays. Now X-rays, like light, and like wireless waves, are vibrations in the ether. They differ in but one respect: they have different wave-lengths. The rate of vibration of X-rays is about 10,000 times more rapid than the rate of vibration of ordinary light; and the rate of vibration of the X-rays themselves is dependent upon the material out of which the target is made. This last statement gives us the key to Moseley's immortal discovery. Using different elements for his target, X-rays of slightly different wave-lengths were produced. The X-rays were passed through a salt crystal and the spectrum so obtained was photographed and studied—in much the same way that we study the spectrum obtained from sunlight when light is passed through a prism. Moseley connected the wave-lengths of the X-rays with the density of the substance under examination; and by a series of calculations into which we cannot enter here, the *atomic number* of the

element was obtained, which proved to be the charge on the nucleus of the atom.* The figures so obtained—the *atomic numbers,* as Moseley called them—were a revelation. If the elements be grouped in the order of their density, the atomic numbers of the first seventeen are as follows: hydrogen 1, helium 2, lithium 3, glucinum 4, boron 5, carbon 6, nitrogen 7, oxygen 8, fluorine 9, neon 10, sodium 11, magnesium 12, aluminum 13, silicon 14, phosphorus 15, sulfur 16, and chlorine 17.

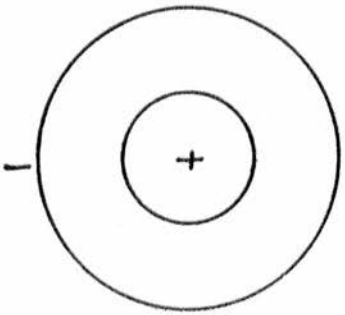
We may proceed right up to the heaviest element of all, uranium, and find that the *difference in atomic number between any two successive elements is one.* One need not be a profound thinker to perceive that when, as a result purely of experimental work, we get numbers for the elements of the order 1, 2, 3, etc., we must be approaching very near to one of nature's profound secrets. "There is in the atom a fundamental quantity," wrote Moseley, in a paper which has since become a classic, "which increases by regular steps as we pass from one element to the next. This quantity

* For those mathematically inclined, Moseley's equation for calculating the atomic number may be given:

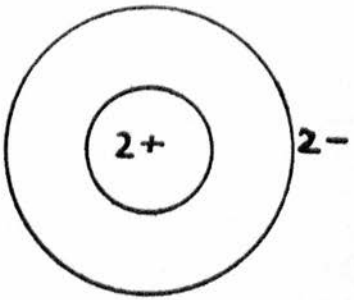
$$V = A\ (N - 1)^2$$

where V is the vibration frequency, A is a constant and N is the atomic number.

can only be the charge on the central positive nucleus.'' The simplest way of representing hydrogen with an atomic number of 1 is



and of helium with an atomic number of 2 is



and so on.

We have endeavoured to answer the first question put by the reader, How do we know how many electrons there are in the outer

circle? We may say, before passing to the next question, that the nuclear charge, or what is the same thing, the atomic number, for a number of the elements has been determined by Rutherford and his co-workers in quite a different way; and Rutherford's numbers agree remarkably well with those obtained by Moseley. Furthermore, the atomic number of an element—which we must define as the number of excess protons over electrons in the nucleus, and which must therefore correspond to the number of electrons in the outer circle—is, as a rule, one-half the atomic weight of the element; the atomic weight representing how many times heavier the atom of the element is than the atom of hydrogen, provided the latter be taken as unity. Thus the atomic numbers for carbon and oxygen, as we have seen, are 6 and 8, respectively; their respective atomic weights are 12 and 16.

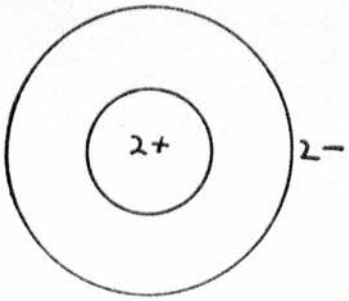
We must now take up the second question asked by the reader—how are the outer electrons distributed? You will remember that the statement was made that the number *and distribution* of these outer electrons regulate the chemical activity of the element. We have already discovered a means of determining the

number of electrons. If to this we can add a picture representing their distribution, we may be able to explain the chemical behaviour of the elements; we may be able, perhaps, to understand, *how* sodium combines with chlorine to form sodium chloride, or common table salt.

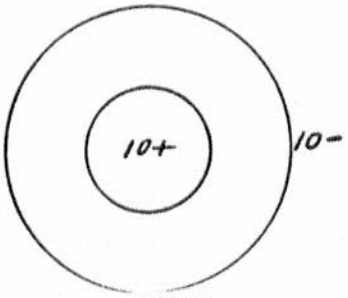
At this point enter Irving Langmuir. You will recall that Langmuir—and Kossel and Lewis—was impressed with the chemical indifference of the "inert" gases—argon, helium, neon, xenon, krypton (and niton); and you will also recall that Langmuir formulated a little theory of his own which postulated that these elements are chemically inert *because their atoms have a stable configuration.* But what configuration? The atomic numbers gave him a key with which to unravel the mystery.*

Let us take the lightest of these inert gases, helium, with an atomic number of 2. The simplest method of representing the element graphically would be

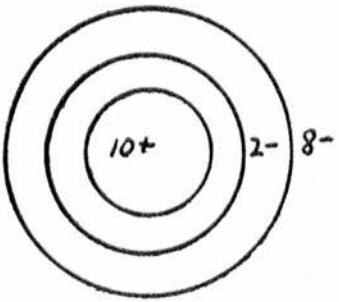
* For various details, consult Langmuir's articles in the *Journal of the American Chemical Society* (volume 41, page 869, 1919) on "The Arrangement of Electrons in Atoms and Molecules," in *Science* (volume 53, page 290, 1921) on "The Structure of the Atom," and in the same journal (volume 54, page 59, 1921) on "Types of Valence." See also Langmuir's article in my *Contemporary Science* (Modern Library, 1921).



Its outer sphere, or "shell," as Langmuir calls it, has 2 electrons; and since helium is the first in the list of stable elements, and, with the exception of hydrogen, the lightest among the elements, we may assume that the *first shell surrounding the nucleus of all elements, except hydrogen, consists of two electrons.* Neon is the next of the inert elements in the order of atomic number. Its number is 10. Here again the simplest way of representing it graphically is



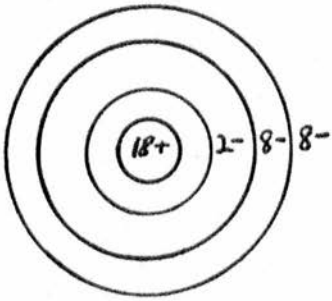
but, according to Langmuir's view, stated in rough terms—for the sake of simplicity of treatment I am omitting many fine considerations—we must consider neon as composed of *two* outer shells, the first with two electrons, like helium, and the second with eight (to give a total of ten electrons); thus



And since we know neon to be an inert element, nature has obviously so ordained it that an element whose first shell contains 2 electrons, and whose second shell contains 8, is a stable element. *Why* this should be so is not so clear, though Langmuir has advanced some ingenious theories to account for the stability of such a system. But whether we can account for it or not, the important fact remains, as we

shall see presently, that with Langmuir's conception in mind, we can account for the chemical activity or chemical inactivity of many elements.

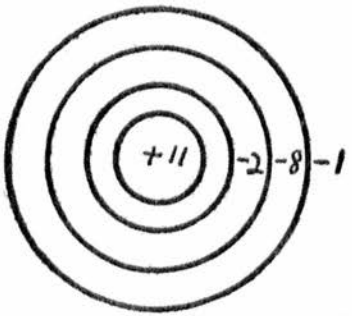
The third inert element in ascending order of atomic number is argon with 18. Its first "shell," according to the theory, must contain 2 electrons, like helium; its second, 8, like neon; and its third, 8, to give us a total of 18; thus



Similarly, we may proceed with krypton, with an atomic number of 36, divided into shells containing 2, 8, 8, 18 electrons; xenon, with an atomic number of 54, divided into shells containing 2, 8, 8, 18, 18 electrons; and niton, with an atomic number of 86, divided into shells containing 2, 8, 8, 18, 18, and 32 electrons.

We are now in a position to turn our atten-

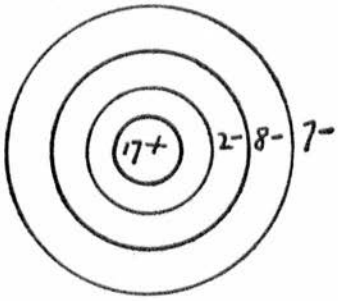
tion to an example—we have chosen for the sake of simplicity, sodium chloride, or common salt —and to answer the question, What constitutes a chemical change? The atomic number of sodium is 11, that of chlorine is 17. Applying the Lewis-Langmuir conception, we may represent sodium thus:



that is to say, its first shell contains 2 electrons, like helium; its second, 8, like neon; but its third shell contains but 1 electron, since its total atomic number is 11. Now, according to Langmuir's theory, an element of this grouping can only be stable, that is, chemically inactive, if its third shell contains 8 electrons. In other words, sodium is an unstable element; it is a chemically active element; it needs 7 electrons to make it stable. Or, it may become a stable

element if it loses 1 electron, for then it would contain but two shells, with 2 electrons in the first, and 8 in the second; and such a system, corresponding as it does to neon, we already know to be a stable one.

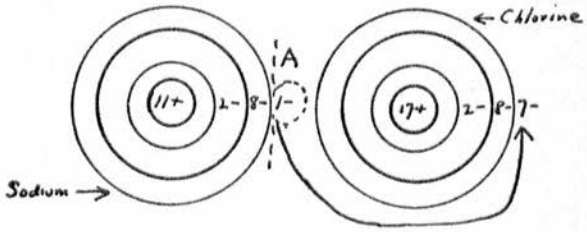
Turn your attention to chlorine. Its atomic number is 17. We may therefore represent it as



The third and last shell contains 7 electrons—another unstable system, and therefore representing an active element, chemically speaking. Here stability, or chemical inertness, or chemical inactivity, may also be reached in two ways: by a gain of 1 electron or a loss of 7 electrons; in the former case assuming the configuration of argon, and in the latter, that of neon.

What, then, happens when sodium and chlo-

rine combine together to form sodium chloride, or, as it is commonly called, common table salt? The following diagram tells the tale:



You see that it is nothing more than the transfer of an electron from the sodium atom to the chlorine atom, thereby producing stable sodium and chlorine systems; or if you will, the sharing by the sodium and the chlorine atoms of the electron marked *A*.

But, you will say, in sodium chloride we cannot recognize either the sodium or the chlorine; we are not aware when we eat soup which has been salted that sodium and chlorine atoms float in the liquid; whereas in the diagram it would appear as if sodium and chlorine are still present as such in the molecule of salt. But examine the diagram a little more closely. When I take an electron away from the sodium atom, what have I left? Obviously, 11 protons and 10 electrons, or + 11 and — 10, giving me a proton

in excess. That is to say, my sodium is no longer electrically neutral, for its atom has an extra proton attached to it; it is no longer Na (Na standing for *natrium*, the Latin word for sodium), but Na +. Na + is sodium charged with electricity; it is an atom charged with electricity; it is an *ion*. Now all the work of Arrhenius and his co-workers has shown us that the properties of the ion are wholly unlike the properties of the atom; that Na is one thing, and Na + is quite another. And the reader may also remember the statement made earlier, that the properties of an element depend, in part at least, upon the number of electrons in the outer shell. Obviously, if we remove one electron, we can no longer expect the atom to show the same properties. In fact, the removal of an electron has practically converted the atom into quite another element.

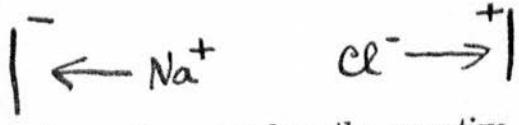
Likewise the chlorine. Here as a result of the union with sodium, we get 17 protons and 18 electrons, or + 17 and — 18, giving us an electron in excess. We are no longer dealing with a chlorine atom, electrically neutral, but with a chlorine atom to which is attached one extra electron, or a negative particle of electricity. The Cl (chlorine) has become Cl —, an

ion of chlorine; and the properties of the ion are quite different from the properties of the atom.

The chemical union, then, of sodium and chlorine consists, in reality, in a transference of an electron from the sodium to the chlorine. You must admit that such a statement satisfies the intellect far more than the one scientists were accustomed to make until quite recently, that the union of sodium and chlorine—the union of any two elements, for that matter—is due to a mysterious "affinity" these elements have for one another.

We must complete our cycle. Before we leave sodium chloride we must explain how it is that not only can sodium and chlorine be made to combine with one another to form sodium chloride, but the latter, in turn, can be decomposed again into sodium and chlorine. The solid sodium chloride (our common table salt) is a very stable substance. You may heat it to a pretty high temperature without decomposing it. But you can break it up into its elements if you first dissolve it in water and then pass a current of electricity through the solution. We have ample evidence for the view that when you take salt and dissolve it

in water, in plenty of water, you no longer deal with sodium chloride as such—with NaCl, to give it its chemical formula—but with sodium ions and chlorine ions; with Na + and Cl —. Merely dissolving salt in water causes the cleavage in the molecule to take place along the dotted line, as shown in the figure on page 116. The salt which we taste in our soup is not sodium chloride but sodium ions and chlorine ions. When an electric current is passed through a salt solution, the ions move towards their respective poles, the positive ions being attracted to the negative pole, and the negative ions being attracted to the positive pole; thus



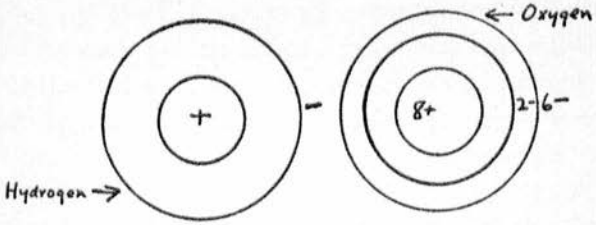
When the sodium reaches the negative pole it receives a negative charge, an electron, and thereby becomes "neutral" or ordinary sodium such as we know the metal. When the chlorine ion reaches the positive pole it gives up an electron and becomes "neutral" or ordinary chlorine such as we know the gas.

So that the series of reactions in which sodium and chlorine first combine to form sodium chloride, and then the latter is separated

into its ions and finally resolved into atoms of sodium and chlorine, hinges on the wanderings of an electron! As profound a chemical change as can be named depends upon a speck of negative electricity!

This theory of Langmuir's does not pretend to be final and complete in detail. There are some reactions which are not easy to explain on this hypothesis; but there are a surprising number of reactions which can be explained. So that the example of sodium chloride may not be considered a tree in the desert, but rather one of many trees in a forest, two other examples will be discussed, water and carbon dioxide; and they are selected in preference to others because, like common salt, they are compounds familiar to the layman.

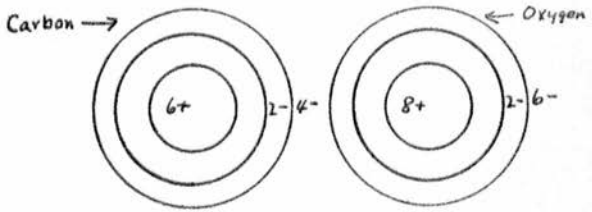
The formula for water is H_2O; that is to say, two atoms of hydrogen combine with one atom of oxygen to form a molecule of water. Both the hydrogen and the oxygen are colourless gases, the one inflammable and the other a supporter of combustion. Water in its natural state, or in any of its adulterated forms, is too well known to need any description. The atomic number of hydrogen is 1, that of oxygen is 8. Applying Langmuir's hypothesis, we have



for the configuration of hydrogen and oxygen atoms. The hydrogen is unstable because it needs one electron to form the first stable shell of two electrons. It may, if it gets an opportunity, grab one electron from another element, or it may give up its electron and remain merely as a nucleus. The oxygen atom is unstable because it needs 8 electrons in the second shell to develop a stable system, and it has but 6. The probabilities are that, already in possession of 6 electrons, it becomes an easier matter for this atom to appropriate two more electrons from some element or elements and establish three stable shells, than to discard 6 electrons and be left with two stable shells. If hydrogen and oxygen are to combine, it becomes obvious that one hydrogen atom can supply but one electron to the oxygen atom; hence two hydrogen atoms will be needed to yield the two electrons which the oxygen atom lacks. Hence H_2O. Here the chemical reaction involved when hydrogen com-

bines with oxygen to form water, is the transference of two electrons from two atoms of hydrogen to one atom of oxygen, the hydrogen and oxygen thereby uniting to form a stable system; or, if you will, the sharing of two pairs of electrons.

Consider carbon dioxide, the formula for which is CO_2. One atom of carbon in this compound is combined with two atoms of oxygen. The atomic number of carbon is 6, that of oxygen is 8. These atoms may be represented as



Carbon may either gain or lose 4 electrons, and the oxygen may either gain 2 or lose 6 electrons in order to form stable systems. One carbon atom, in a position to yield 4 electrons, will need two oxygen atoms for combination, since each oxygen atom lacks two electrons for a stable system. Hence CO_2. Hence the burning of carbon in oxygen to form carbon dioxide may be looked upon as a chemical reaction involving the transference of 4 electrons from one

carbon atom to two oxygen atoms, the carbon and oxygen uniting to form stable systems; or, if you will, the sharing of four pairs of electrons.

The ordinary chemical reactions, the reactions which take place with comparatively little effort, are due then to the constant desire of the atoms of relatively unstable elements to form stable systems, stability or instability of the atom being determined by the number of electrons in the outer sphere.

The electron is at the very heart of every chemical reaction; which means that it is at the very heart of life itself.

CHAPTER XII

SCIENCE AND LIFE: THE ORIGIN OF LIFE

The trouble with Einstein and his relativity is that the earth is much too small for him; the trouble with Rutherford and his atom is that the earth is much too big for him. Relatively speaking, the atom is to the earth what the earth, perhaps, is to the cosmos as a whole. The triumph of modern science can, in a sense, be epitomized by saying that it has invented new eyes to see and new ears to hear; or, to be more exact, that it has brought within our ken what was beyond our range before. No yardstick can measure an atom whose diameter is one-three-hundredth of an inch; yet the physicist has found ways of measuring the size of atoms. No ultra-microscope is powerful enough to reveal to us the existence of an atom; yet the physicist is as certain of the reality of atoms as he is of the reality of his own existence. The secret of his success lies in this: that the instruments which he has invented make atoms (and their constituents, the electrons) perform

"stunts" which our eyes can see; so that, though we are denied a view of the atom and its interior, we can outline, in a somewhat crude way, the general design of the house.

The latest details in the space-structure of the atom are supplied by Professor Bohr, a young Dane, who explains, with the help of his theory, why the elements give the characteristic spectra they do. The theory is a very difficult one to explain; * but Lodge, in his book,† makes it as intelligible as it can be made to a non-mathematical reader. Bohr's theory, in turn, rests upon a discovery of the Berlin physicist, Planck, that light, X-rays and other forms of radiation are sent out not in continuous waves, but in definite "shots" called "quanta." "Why the radiation emitted by atoms should thus be distributed in packets," writes Lodge, "is not yet fully known; but we are certain that it has something to do with the internal structure of the atom. And we are now prepared to admit that an unexpected discontinuity, running through the whole of atomic science, and therefore essentially through the whole of matter, has been discovered. . . . Exploration of the

* For those who want to try, see N. Bohr: *The Theory of Spectra and Atomic Constitution* (1922).

† Oliver Lodge: *Atoms and Rays* (1924).

structure of the atom is a quite recent quest. Fifty years ago we did not suspect that the atom had a structure. It seemed a hard, unbreakable, exactly patterned geometrical solid, like a 'manufactured' article. Twenty-five years ago we doubted this, but still had no idea what the structure was. Now we analyze it into a regular group of points or specks, each having a definite small mass and an equally definite but a great electric charge. These specks, of which the structure is not yet known, have great interspaces between them, and we apply to the motion of those specks, in the comparatively vast space inside the atom, the laws of astronomy. . . . We are living in the dawn of a kind of atomic astronomy which looks as if it were doing for chemistry what Newton did for the solar system."

Let your imagination roam a little as you think of the beginning of things, with its free electrons and protons; some of these electrons and protons, in time, unite to form hydrogen and helium atoms; then, in the course of time, some of the hydrogen and helium unite to form the various elements; then the elements unite, first to form simple inorganic compounds and later more complex inorganic compounds; then the complex inorganic compound slowly

emerges as the simple organic substance; and this, in turn, works its way into an ameba—and life!

Is such the origin of life? "Problems of life are problems of matter," says Schäfer. "To me the meanest flower that blows can give thoughts that do often lie too deep for tears," says Wordsworth.

The ultra-scientific school, at the head of which are Loeb and Schäfer, trace the origin of their ideas chiefly to Huxley. As far back as 1870 this philosopher wrote: "With organic chemistry, molecular physics and physiology, yet in their infancy, and every day making prodigious strides, I think it would be the height of presumption for any man to say that the conditions under which matter assumes the properties we call 'vital' may not, some day, be artificially brought together."

That was before Emil Fischer began his work on the structure of the protein molecule; before Kossel commenced his celebrated investigations into the composition of nuclear material; long before Loeb startled the world with his experiments on parthenogenesis. With that intuitive spirit with which he was singularly gifted, Huxley foresaw—so claim our ultra-scientists—the results of modern research. Our chemistry,

our physics, our physiology, have already reached that stage where we can say with confidence: the data necessary is within sight. Within these three sciences a complete explanation is to be found. Hence, outside factors need not be considered.

True, the mere fact that they can give no satisfactory definition of life can be of little avail in the present controversy. Spencer's definition establishes its mystery: "Life is the continuous adjustment of internal relations to external relations." However, it may be argued that we can do no better in the case of electricity, and yet our control of that is well-nigh complete.

It should be made clear, in justice to our ultra-scientists, that their aspirations at present run no higher than to bring the phenomena of life within the category of established laws. Their aim is to regulate forces. To understand them is, they admit freely, beyond their ken. Thereby, even if their own problem were solved, a purely materialistic view would hardly be appreciably advanced.

But to return. Life, like electricity, cannot be defined, but, like it, manifests itself in certain ways. Movement, metabolism, growth and reproduction are held to be properties of life by a

large class of physiologists; but the insurgent group, with Wöhler's artificial production of urea as its foundation stone—wherein he overthrew the idea that organic substances possess a "vital" force—is bent upon showing us that there is no such barrier between the animate and the inanimate. Is it movement that you are considering? Have we not that in organic mixtures, in oil drops, in globules of mercury? And are these not all explicable by changes in surface tension? Is it metabolism—the taking in of food and the giving out of waste products? If so, what of osmotic conditions, where solutions are separated by semi-permeable membranes and where there is an interchange of substance? Is it growth and reproduction? If so, consider the growth and multiplication of crystals.

It is this argument by analogy that has led the ultra-scientific school to its present theory with regard to the origin of life. Rightly brushing aside the meteoric theories of Kelvin, Helmholtz and Arrhenius as irrelevant in so far as origin goes—for in their attempt to explain the first sign of life on this planet they presuppose the existence of the germ elsewhere—Schäfer boldly upholds the hypothesis that life originated as the result of a gradual evolution of in-

animate material. In process of time the simple substance became more and more complex and ultimately emerged as the living germ—the nitrogenous colloid.

But Schäfer goes a step further. Why are we to suppose that this happened but once, as all theories with regard to origin have thus far assumed? Why are we to suppose that one time in the distant past a series of fortunate accidents made life possible? Is it not more logical to assume that these evolutionary processes are going on to-day and will continue to do so? *

Though even Huxley was of the opinion that at one time there was "an evolution of living protoplasm from not living matter," the idea that we should not relegate the process to some remote period in the past is a comparatively new one, and has not by any means received the approval of many otherwise loyal chemico-physiologists. These argue, with no small show of reason, that continuous life production would imply similar terrestrial conditions throughout the ages; and this we know not to be the case. Giving fancy full reign, Macallum, the Canadian bio-chemist, pictures for us "a gigantic labora-

* Sir E. A. Schäfer's article has been published, among others, by the Smithsonian Institution, *Smithsonian Report, Publication 2213*, under the title "Life: Its Nature, Origin and Maintenance."

tory where there had been a play of tremendous forces, notably electricity, which might have produced millions of times organisms that survived but a few hours, but in which, also, by a favourable conjunction of those forces, what we now call life might have come into existence." No less fanciful is the English chemist, Armstrong.*

As growth and multiplication are by far the most characteristic features of the living organism, it is little wonder that the fiercest antagonism centres around this point. Mitchell, one of the mildest critics, takes exception to the crystal comparison, on the ground that living matter is a mixture of substances chiefly dissolved in water, and that therefore it would be far more appropriate to take liquids as the basis for comparison. Armstrong and Haldane, the one a chemist and the other a physiologist, and both among the most eminent in their respective professions, flatly refute the analogy. In crystal growth there is a mere piling up of simple units, and, under proper conditions, there is no limit to the growth of the crystal. Nothing corresponding to cell division, nor to the complexity of organic growth, is ever met with. Berg-

* H. E. Armstrong: "The Origin of Life: A Chemist's Fantasy," *Smithsonian Report, Publication 2214.*

son, whose knowledge of the exact sciences makes him an exceedingly competent critic, argues that whereas the living organism is composed of unlike parts and performs diverse functions, the crystal neither consists of the one nor performs the other. "Crude materialism," writes the more violent Schopenhauer, "stupidly denies vital force, and tries to explain the phenomena of life from physical and chemical forces, and these again from the mechanical effects of matter. But I will never believe that even the simplest chemical combination will ever admit of mechanical explanation."

Bergson repudiates Schäfer's whole hypothesis, but in this he is in agreement with many a scientific authority. For example, Professor Wilson, whose book on cell development is a classic, sums up his views in these words: "The study of the cell has, on the whole, seemed to widen rather than to narrow the enormous gap that separates even the lowest forms of life from the inorganic world." Sir William Tilden, the English chemist, is equally emphatic from the chemical standpoint. He writes: "Far be it from any man of science to affirm that any given set of phenomena is not a fit subject of inquiry, and that there is any limit to what may be revealed in answer to systematic

and well-directed investigation. In the present instance, however, it appears to me that this [the origin of living matter] is not a field for the chemist, nor one in which chemistry is likely to afford any assistance whatsoever." *

Let it at once be stated clearly and emphatically that the ultra-scientific view is based primarily upon analogy—a very valuable method provided it is not carried to excess, and provided, also, sufficient experimental data are at hand. Mendeléeff's periodic classification tended to show that cesium, rubidium, sodium and potassium were closely allied, a fact which was, however, known before Mendeléeff's time purely as a result of experimental work on these elements. The movement of oil drops and the interchange of substance in osmosis are certainly quicksand foundations upon which to build inter-relationship theories of the animate and the inanimate. This superficial connection fails to stand the test of adaptation and co-ordination—to name two characteristic features of the *vital* substance. Indeed, our knowledge is so remarkably extensive that we cannot as yet

* For some references, see H. Bergson's *Creative Evolution* (1911), page 12; E. B. Wilson's *The Cell in Development and Inheritance* (1907), page 330; P. C. Mitchell's article on "Life" in the *Encyclop. Brit.*, 11th ed.; and H. H. Newman's *Outlines of General Zoology* (1924), page 31.

state the simplest *vital* manifestation in terms of science.

But this does not make a discussion of this kind any the less valuable. The impetus to research that it gives is productive of the highest good to mankind, for if the results do not solve the problem, the *scope* of the problem becomes so much clearer. The whole, which is made up of many co-ordinated components, eludes the grasp, but the individual components are gradually revealing many of their secrets to the untiring scientific explorer. With the physiologist ever attentive in his study of the human mechanism, with the chemist carefully analyzing and synthesizing the more complex forms of matter so intimately associated with life's activity, with the scientific philosopher investigating the laws common both to animate and inanimate substances, who would venture to foretell the outcome?

The present situation may perhaps be summed up in some such way as this: 1. Chemistry and physics may possibly contain all the necessary factors, our ignorance being due to our inadequate knowledge of these sciences, especially chemistry; or, there may be an outside factor. 2. While no definite theories as to the origin of life can as yet be advanced, it is

not unreasonable to suppose that in process of time, a better insight into chemistry, physics, or the outside factor will be obtained. Fancy may well picture even the acquirement of new faculties, which will bring within range many of nature's present secrets, unattainable by present methods. 3. At present we know of no better way of pursuing our search than through the sciences. But here we are safe only when we apply them to the things we can grasp. The application of scientific methods to the spirit world (the methods of Richet, Crookes, Lodge and others) have thus far been barren of result. Science, as we understand it, rules in the world of matter, but it does not beyond. Whether this "matter" is but a manifestation of the "spirit," whether there is any relationship between them, or whether, indeed, they spring from the same source, time may, and time may not, tell. We may, if we want to, agree with Schopenhauer when he insists that we cannot explain mind as matter because we know matter only through the mind.* In any case, our task is to plod the weary way, irrespective of where it leads to, or what the outcome of it may be.

* See W. Durant: *The Story of Philosophy* (1926).

CHAPTER XIII

SCIENCE AND LIFE: THE APPLICATION OF SCIENCE

One of the results of the war was to push science near to the forefront of the world's stage. The effect of science upon civilization—will civilization be destroyed by science or will it be uplifted?—is being discussed everywhere. The war has shown the dark side of science—the danger which arises when matches are put in the way of infants. Many of the more reflective among us, realizing what an utterly irresponsible crew we human beings are, are aghast at the possibilities which science has opened up for us. Man is by nature evil-minded, these pessimists tell us; put TNT into his hands and he much prefers destroying his fellow-creature to building a Panama Canal.

The optimists agree with the pessimists in believing that progress in science has been altogether out of all proportion to progress in ethics; but they believe that science is bound, sooner or later, to raise the moral plane of mankind. Haldane, Reader in Bio-Chemistry at

Cambridge (related to the statesman who dabbles not unsuccessfully in philosophy), takes this view.* Giving his imagination freer rein than even some poets do, he prophesies a rosy future for mankind when biology will replace the physical sciences in their influence upon us, and Kantian idealism will reign supreme. The blessed day is probably far off. There will be wars and more wars, each one more deadly than its predecessor. Even here science will render service of a constructive kind, though in an indirect way; for it will so magnify injustice, by inventing any number of death-dealing instruments, that the situation will become too intolerable to be borne, and man will then destroy the roots of the evil. In the meantime, science will not only have conquered space, time and matter, the "matter" of the human body, but it will be on the eve of conquering the "dark and evil" elements within man. Then will come the millennium, or something very near to it.

Not so, says Russell. The English philosopher and mathematician and politician and scientist sees nothing but darkness ahead of us. "Much as I should like to agree with his [Haldane's] forecast, a long experience of statesmen and Governments has made me somewhat skepti-

* J. B. S. Haldane: *Dædalus* (1924).

cal. I am compelled to fear that science will be used to promote the power of dominant groups, rather than to make men happy. Icarus, having been taught to fly by his father Dædalus, was destroyed by his rashness. I fear that the same fate may overtake the populations whom modern men of science have taught to fly." *

Science, explains Russell, may act in one of two ways: It may increase man's power of gratifying his desires without altering his passions; or it may influence his philosophy and theology. So far the influence of the former has been much greater than that of the latter. Furthermore, neither the biological nor the anthropological sciences have so far forced themselves upon us to any extent. The physical sciences have, however, affected us profoundly. In consequence of scientific inventions which facilitate centralization and propaganda, groups become more organized, more disciplined, more group-conscious, and more docile to leaders. The effect of leaders on followers is increased, and the control of events by a few prominent personalities becomes more marked. In all this there would be nothing very tragic, but for the fact, with which science has nothing to do, that organization is almost wholly national. "Sci-

* Bertrand Russell: *Icarus* (1924).

ence has determined the importance of raw materials in international competition. Coal, iron and oil are the basis of power and then of wealth"; and modern industrialism is a struggle between nations for raw materials (and markets, and for "the sheer pleasure of dominion"). The struggle between industrialists representing national groups, in their attempts to grab coal and iron and oil, leads inevitably to disputes between nations—and to war. Once war is declared, the pliant servants who first disclosed to their masters the riches of the earth are now employed in destroying everybody except their masters and their satellites, the politicians and diplomatists.

For much of this destruction the servants themselves must be held responsible. The scientists serve their masters without questioning. The scientists have a "scientific" but not a "political" compartment in their brain. They work most faithfully in their laboratories, bringing to bear upon their problems an imagination and a skill which are the glory of mankind; but they allow their inventions and discoveries to be stolen from them by men saturated with a mixture of lust and power, in whose hands the very gods are transformed into devils.

Since national organization leads to rivalry and to war, an obvious remedy would be to substitute an international for a national organization. This gives Russell an opportunity to pay his respects to Wilson's League of Nations: "Political internationalism such as the League of Nations was supposed to inaugurate, will never be successful until we have economic internationalism, which should require, as a minimum, an agreement between various international organizations dividing among them the raw materials and markets of the world. This, however, can hardly be brought about while big business is controlled by men who are so rich as to have grown indifferent to money, and to be willing to risk enormous losses for the pleasure of rivalry."

Long before "big business" will have lost its influence it is quite conceivable that physiologists may make, and probably will make, discoveries which will but strengthen the hands of the money kings. Take the subject of glands —the glands that make you or unmake you, that make you fat or make you thin, that make you wise or make you foolish—"physiology will in time find ways of controlling the emotions. When that day comes we shall have the emotions desired by the rulers, and the chief

business of elementary education will be to produce the desired disposition, no longer by punishment or moral precept, but by the far surer method of injection or diet. . . . The State could give to the children of holders of power the disposition required to command, and to the children of the proletariat the disposition required for obedience. Against the injections of the State physicians the most eloquent socialist oratory would be powerless."

The views of Haldane and Russell are not really in direct opposition, though a superficial reading of *Icarus* would lead us to believe so. Haldane believes that the immediate effect of science will be bad—that it will bring on more wars and more destruction; but ultimately science will emerge as the cleanser of man's soul and the saviour of mankind. To save mankind may take several thousand years, but to the student of geology such a period is merely a drop in the bucket. Russell believes with Haldane that the more immediate influence of science will be one which leads to destruction, but destruction to such a degree as to wipe us off the map altogether.

The prophecies of these Cambridge scientists do not, this time, come within the circle of prophecies in science. They are merely the

opinions of erring mortals; they may be right, and then again they may be wrong. However, much that they say seems plausible enough. Plausible, indeed, is their view, shared by students everywhere, that if the ever-increasing discoveries of science remain in the service of the types of men who were instrumental in bringing about the Great War, future populations have even greater sufferings in store for them than the sufferings of the present generation.

But the scientist cannot stop. Whether he wants to or not, a force over which he has no control urges him on his road of discovery. If the world misunderstands and misapplies what he has to offer, so much the worse for the world!

"Science," as Robinson points out,* means to most people our knowledge of things other than man. Man's behaviour until quite recently, has been exempt from scientific scrutiny and "there is no field of reputed knowledge where dogmatism is more arrogant and ignorance more complacent"; and yet, when examined critically, a study of man's behaviour is as much a science as a study of the behaviour of atoms in chemical changes. "Science should include all the care-

* James Harvey Robinson: *The Humanizing of Knowledge* (1926).

ful and critical knowledge we have about everything of which we can come to know something." Even more important than the discoveries in science is the scientific mood—the critical attitude which takes nothing for granted and which starts out with no preconceived notions. "The scientific mood," writes Robinson, who should be acclaimed as the foremost scientific interpreter of the age, "is after all nothing more than a persistent ambition to find out as well as we may how things really stand. . . . It is but another name for intelligence." And yet "intelligence" in this sense is the privilege of few. Most "educated" people are not "intelligent" at all. Many of the scientists who unhesitatingly—I was going to say "automatically"—apply the scientific method in their experimental researches, fail miserably when facing social problems. The *success* of a new observation depends little upon its scientific or historical associations. "The wonder grows that there ever appeared in this world of ours a group of men so eccentric as to regard truth as the paramount issue." These men "crave a meticulous precision of observation, measurement and statement quite alien to the other teachers of men. They exhibit an almost shocking insensibility to the cherished motives of be-

lief. They do not ask whether what is sought is either right or wrong, beautiful or ugly, useful or futile, comforting or distressing. They only ask whether what is found is an instance of something really happening."

Profoundly affected as we are by scientific knowledge, is it wise to allow ourselves to be guided by men who are not only woefully ignorant of science, but, what is worse, have a contempt for it and for the "scientific attitude"? Such men—the men in authority—are the supervisors who prescribe what is to be taught and what is to be told. They tell us, in defence of their unpardonable ignorance, that it is not "safe" to invite the "masses" (or the young) to think of important matters with a critically open mind. Hence we get, for example, a distortion of American history which we ask our young to absorb; as if a faithful account of American pioneers, recording not only their successes *but their failures,* were not a more wholesome lesson than distorting the truth. Why, to use an expression of Dickenson,* must we "drug our mind with passion" until we reach the very anthithesis of truth? † Because

* G. Lowes Dickenson: *A Modern Symposium* (1923).

† Within the last few days (August, 1926) the British Government has refused to allow a speech of Bernard Shaw's to be broadcasted on the ground that it might deal with con-

people have been led to resist thought as they resist death. While to think and not to live is to live an incomplete life, to live and not to think is really not to live.

troversial subjects. And many centuries ago the Athenian authorities persecuted an equally illustrious citizen, Socrates, for much the same reason.

CHAPTER XIV

SCIENCE AND LIFE: THE SCIENTIST AS CITIZEN

Dr. W. A. Noyes is professor of chemistry at the University of Illinois. He is a chemist of sufficient distinction to have been President of the American Chemical Society. Like Frederick Soddy, the Oxford scientist, Noyes has been impressed with the point of view expressed by Galsworthy that since scientific men have made war so destructive, they were under an especial obligation to do something to prevent further wars. To contribute to this end, Professor Noyes has spent his sabbatical year in Europe, exchanging viewpoints on the political situation with French and German scientists. A record of these conversations merely strengthens the conviction that in politics the majority of scientists think like the masses at large.*

Professors Marie and Moureu, representatives of French chemistry, declare that despite the seizure of Alsace and Lorraine in 1870, the

* See W. A. Noyes: *Building for Peace* (Chemical Catalog Co.).

French did not harbour any designs against Germany. On the contrary, Germany, bent upon world dominion, deliberately started the war of 1914 to crush her rival beyond recognition. The violation of Belgian neutrality, the atrocities committed by Germans in Belgium and France, the publication of the Manifesto signed by 93 German "Gelehrten," the attempts to break at all cost every provision of the Treaty of Versailles, the stocks of concealed arms found in various parts of the Empire, the ever-changing Green Police, which, in reality, form the nucleus for a large and well-disciplined army, all point to German ruthlessness and to a spirit which changes not with defeat and with time. A nation which not only makes grievous mistakes, but refuses to acknowledge these mistakes and to show any signs of repentance, cannot be trusted. Hence the necessity for a large standing army in France. Hence the necessity for the expenditure of large sums of money which might otherwise be used to far better purpose.

It is Dr. Marie's contention that what is true of the German nation is doubly true of the German scientists. During the war they supported with acclaim every conceivable brutality committed by the German army. He charges them

with being directly responsible for the war and for the "collective soul" which they had created.

These attacks are answered by Professors Willstätter and Wieland, prominent German chemists. They believe that France entered the war primarily to recover the two provinces lost in 1870. They believe that France cleverly manœuvred her diplomatic policy to involve first Russia and then England; and that Germany struck in self-defence only when she found herself at bay surrounded by hostile groups. Since the war France has been consistently hostile to any suggestions which might lead to German recovery. France is bent upon holding the Ruhr and all the country on the west bank of the Rhine, upon forming a Rhenish republic, upon separating Bavaria from Prussia, upon dismembering the Germany that remains, etc., etc.

As to the attitude, more specifically, of German scientists, Professor Willstätter points out that while bitter attacks on Germany appeared in the *Comptes Rendus* in the fall of 1914, no such attacks appeared in German scientific publications. He also contrasts the erasure of the names of German chemists from the honour rolls of scientific societies in enemy countries with the decision of the German Chemical So-

ciety not to erase the names of chemists belonging to hostile nations. The obvious conclusion Professor Willstätter wishes us to draw from these examples is that the German scientist never forgot that he was a scientist.

These parry-and-thrust arguments cannot lead very far. They are the outburst of passion-fed men repeating what has been drilled into them. But when the subject of poison gas is approached, there the French scientist is convinced that the German scientist hasn't a leg to stand upon. For what could more clearly show the depths to which the German scientist has fallen than the introduction, at his suggestion, of poison gases in warfare? Where in the annals of history do we find a bad cause supported by worse means? To this charge we have a reply from Professor Haber, who was in command of the German Chemical Warfare Service. As this is the first time that a statement from so authoritative a source has reached us, it might be well to quote Haber:

"At the beginning of the war it is certain that among the weapons with which the French entered the war were rifle grenades filled with bromacetic ester (a poison gas). From August 1, 1914, to April 22, 1915, we have always had

in mind the possibility that the French would use gases because, from the beginning of the war, the enemy press gave us to believe that the French prepared and used such war materials. I have a number of press clippings which show that such weapons were reported on the side of our enemy. In February, 1915, the French minister of war gave out to the soldiers printed service directions for the use of gas weapons. I have myself seen these directions. Since success was to be expected only on a large scale, and artillery was not sufficient, we introduced the method of blowing the gases over; and on April 22, 1915, clouds of chlorine were blown over at Ypres."

To this, the French chemist, Grignard, replies: "As to the use of asphyxiating gases, I can tell you that the Government had no stock of them. There was only a small amount of bromacetic ester for the police of Paris, who used it to overcome thieves or madmen who barricade themselves in their apartments. It was not with that at all that we could start a war."

Again, where are you? In any case, if you agree with the head of our own chemical warfare service that the use of poison gases in warfare is humane, because while it tends, temporarily,

to disable many fighters, it kills relatively few, then the Nobel Peace Prize should go to Haber or to whoever else is responsible for the introduction of so humane a weapon in warfare. And the head of the chemical warfare service now receives support from another quarter. Dr. Norris, President of the American Chemical Society and Professor of Organic Chemistry at the Massachusetts Institute of Technology, speaking before the Institute of Politics at Williamstown (August, 1926) said: "Of casualties by gas in the World War, 2% resulted fatally, and of the casualties by other means, 25% resulted fatally." I have not yet heard either general or chemist, in Allied countries or in the Central Empires, seriously dispute such figures. They are probably quite near the truth.

Professor Noyes's attempts to bring the scientific men together again are laudable, but, so far as I can judge, get you nowhere. If peace continues for any length of time, the French and German scientists will get together just as they did after the Franco-Prussian war, and irrespective of what men like Noyes may do; and if war comes again, the scientists will part again, and again call one another names, just as they did during the Franco-Prussian War and during the Great War—again irrespective of what

men like Noyes may do. As I write these words (August, 1926), news comes that the German, Austrian and Bulgarian scientists have been asked to join the International Union of Science, an organization formed soon after the Treaty of Versailles by scientists belonging to Allied countries, one of the avowed purposes of which was to exclude from membership scientists belonging to the Central Powers. And within the last few months our own American Chemical Society has restored to honorary membership several eminent chemists of the Central Empires whose names were stricken from the membership lists at the time we entered the war.

During the Franco-Prussian War conditions were no better. The great Pasteur, who received an honorary M.D. degree from the University of Bonn in 1868, returned the diploma in 1871 with the comment "the sight of that parchment is odious to me." "Every one of my future works," he writes elsewhere, "will bear on its title-page the words 'Hatred to Prussia. Revenge! Revenge!' " And the dear old soul set about revenging himself by trying to make French beer superior to the German variety!

The fierce nationalism of the seventies and of our own day was apparently not so deeply ingrained in the people of the Napoleonic era, for

we find, for example, that Sir Humphry Davy received a prize from the French Government for his invention of the safety lamp during the years when England and France were at war; and during this same period Jenner, whose name will forever be associated with the story of vaccination, was elected a Corresponding Member of the National Institute of France.

The complex motives that make war possible are completely overlooked by Noyes and his French and German chemical friends; they may be found in, among others, Lowes Dickenson's *The International Anarchy, 1904–1914* (1926), in which the real causes underlying the World War are scientifically reviewed. Here "diplomacy" gets its full share of credit; the "diplomacy" which has been matchlessly summarized by the master of the art, Bismarck: "All politics reduces itself to this formula—try to be *à trois* as long as the world is governed by the unstable equilibrium of five Great Powers." The more immediate, if superficial, reason for the outbreak of the World War was, of course, the assassination of the Archduke Ferdinand. A judicial question, such as, Who killed the Archduke Ferdinand? developed into an excuse for the wholesale slaughter of innocents. The peasant Karl kills peasant Jean; and worse still,

the physicist Alfred kills the poet Albrecht. Accident of birth might have made Karl a Frenchman, Jean a German, Alfred an Austrian and Albrecht a Russian. With neither more nor less cause—with no personal grievances but with hatred in their hearts instilled wherever and whenever required—Karl would now kill a German and Alfred an Englishman. Or, if the war had come in 1901—as it might well have done—when England and Germany were drawing towards an alliance, then Karl and Alfred would have joined hands in killing or being killed by Jean and probably by Vladimir.

I once asked one of those easily misled individuals, a bubbling-over patriot, what he (an Englishman) would have done had he been born a German? "What every decent German did—I would have gone to fight," he flashed back. And then he thought a minute. "But I could *never* have been born a German," was his parting shot of wisdom.

As early as 1915 (*New York Times,* August 7), I wrote:

'The difficulties we experience at all times in examining a situation thoroughly and impartially are strikingly brought home to us during

the present war. Throughout the first ten months of the conflict the world busied itself in an attempt to fasten the guilt of the war upon some one particular nation. The Germans blamed England, the English blamed Germany. Now, perhaps, we are in a position to decide the issue in Sir Roger de Coverley's way: 'There is much to be said on both sides.' It is impossible to say which nation is guilty, for all the contending nations are more or less guilty; it is impossible to say which nation is innocent, for none is. If a comparative scale is to be applied we must adopt bad, worse, not bad, better, best. Miss Addams rightly emphasizes what has been touched upon by several close observers, that the people of the various warring nations use identical phrases in defending the stand taken by their respective countries. Whatever justice there is, is fairly evenly distributed."

To go to war instead of going to court is to force us to believe that despite endless years of evolution and two thousand years of Christendom, man is still a barbarian. The ghastly joke is that war never decides in favour of either of the combatants, if by "combatants" we mean

the "people." No people, claims Santayana, has ever won a war. Do not the results of the biggest of all wars support this thesis?

The problem of war and peace is not insoluble, but it just happens to be the most difficult problem in the world to solve. Admitting the view expressed by Soddy that scientific men stand for something in the world higher than anything which has as yet found expression and representation in governments, particularly in their international relations, the very first task which confronts scientists is to continue to think scientifically *after* they have left their laboratory. Robinson in his *Mind in the Making* and in *The Humanizing of Knowledge* appeals for the scientific spirit among the masses at large. My contention is that the scientific spirit must first be engendered among the scientists themselves, *for them then to spread the gospel.* They must be taught to regard the scientific method as one applicable to a universal outlook on life and not merely to a chemical reaction. It follows from this that once such a view has become firmly entrenched, the fundamental difference in method between scientist on the one hand, and non-scientist (including industrialist, diplomat and politician) on the other, will become apparent. It will no

longer be possible for the type of men who at present control the destinies of the world to misuse the glorious inventions and discoveries of science. At least, one may confidently look forward to a death-struggle between two schools diametrically opposed to each other.

THE END

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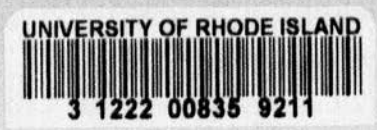

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